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Oceans

WELCOME

According to the Ordinance Survey, the coastline of the United Kingdom measures 11,072 miles. That's greater than the distance from London to the South Pole, and highlights why even the most avid enthusiast of the deep blue sea continues to be enthralled by the oceans. There's always something new to inspire, whether that's recently-discovered species of plant and animal life, or diving into waters in search of pushing humans to their limits. Cue our freediving feature (p106).

Within your aquatic guide, we trawl history and the planet to serve up the greatest tales from the ocean. In our geology section, discover how oceans were formed four billion years ago (p18); our sea animal chapter reveals how jellyfish can morph into their juvenile state (p48); sharks deservedly earn their own chapter from page 68 – we wouldn't want to disrespect the great white; man's exploration of the sea begins on page 90, including technological breakthroughs to enhance our oceanic knowledge (p112); and we conclude with how man's looking to save the seas from years of polluting maltreatment – by man.

Enjoy your special guide to the oceans. We hope it inspires you to engage with arguably nature's greatest achievement.

JAMES WITTS
Editor, Discover Science

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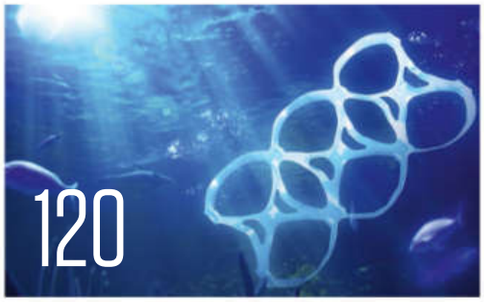

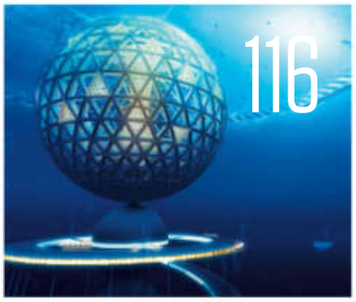

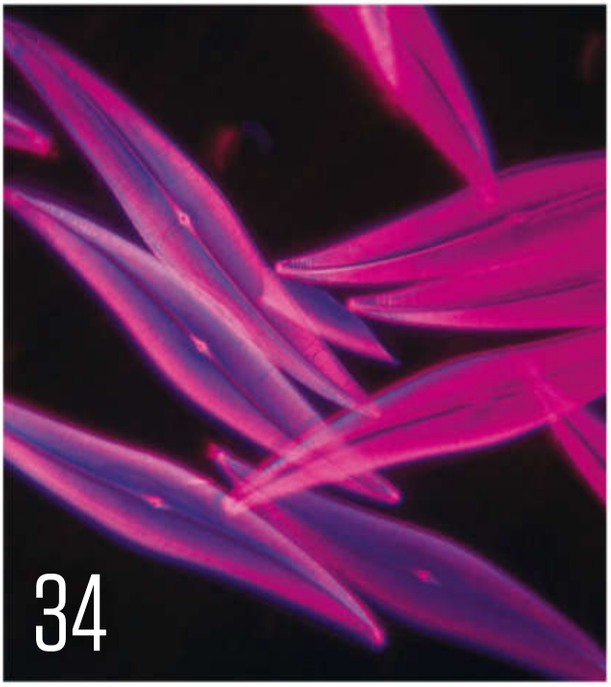

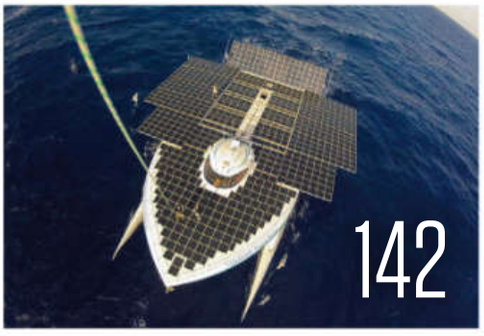

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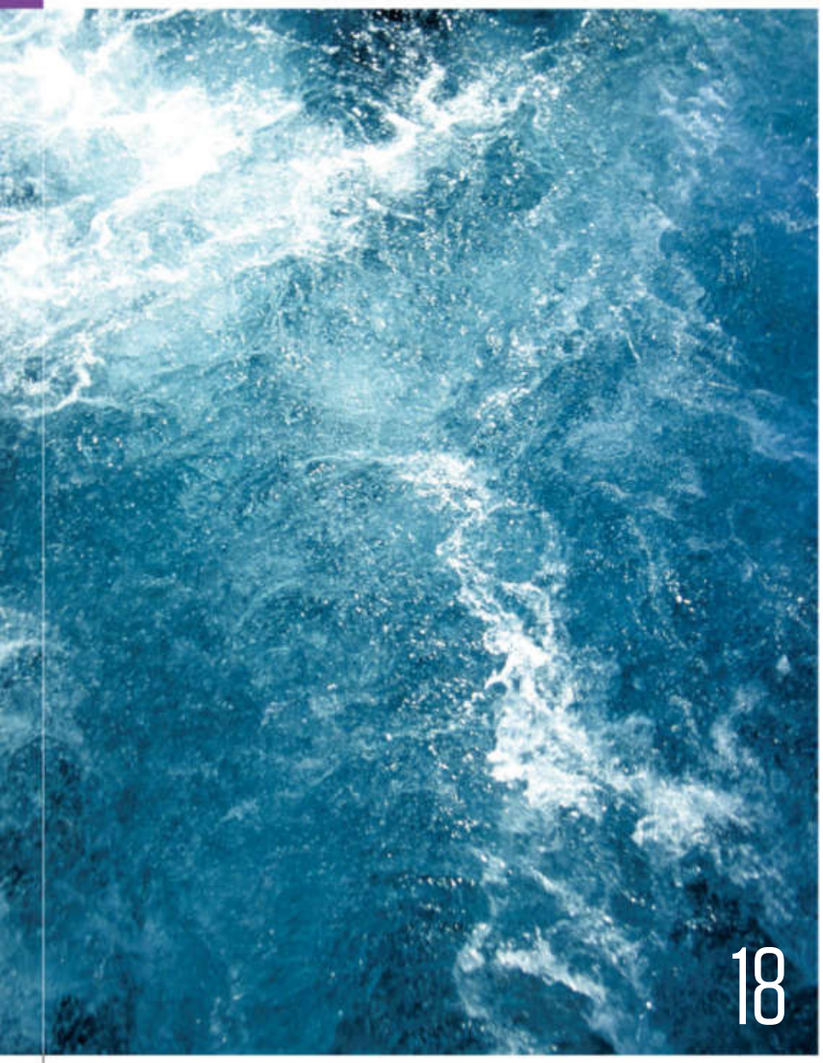

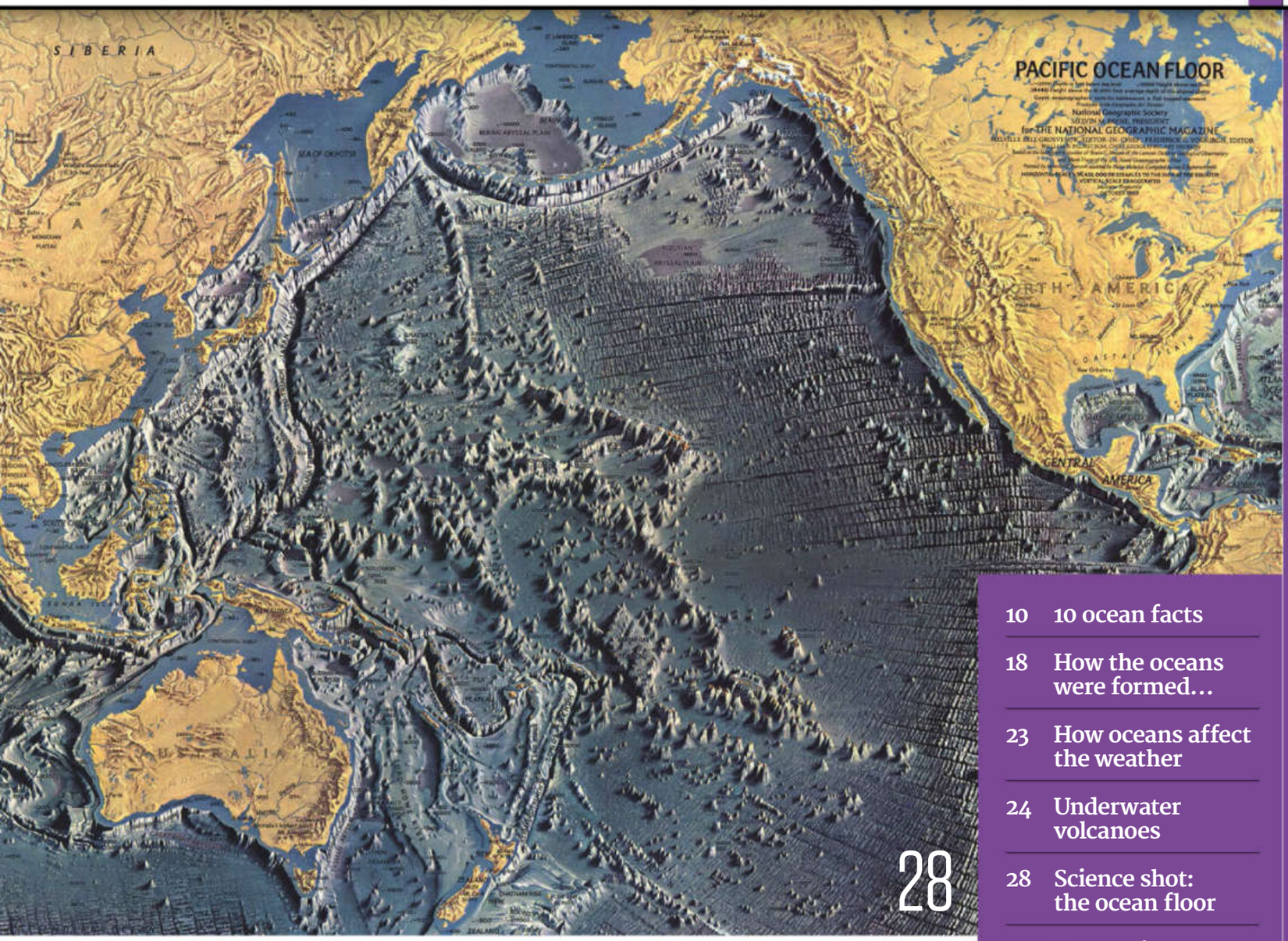

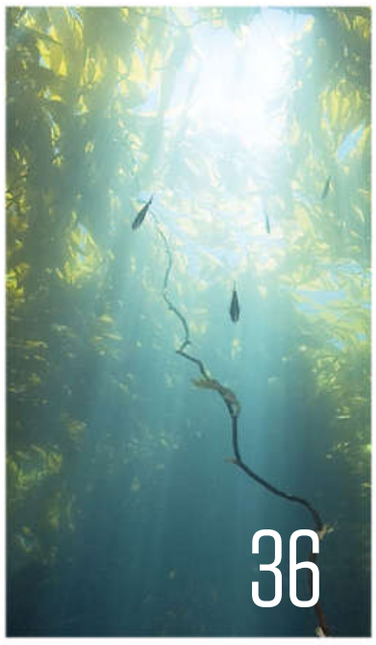

"OCEANS FORMED ABOUT 3.8 BILLION YEARS AGO AT THE END OF THE HADEAN EON"

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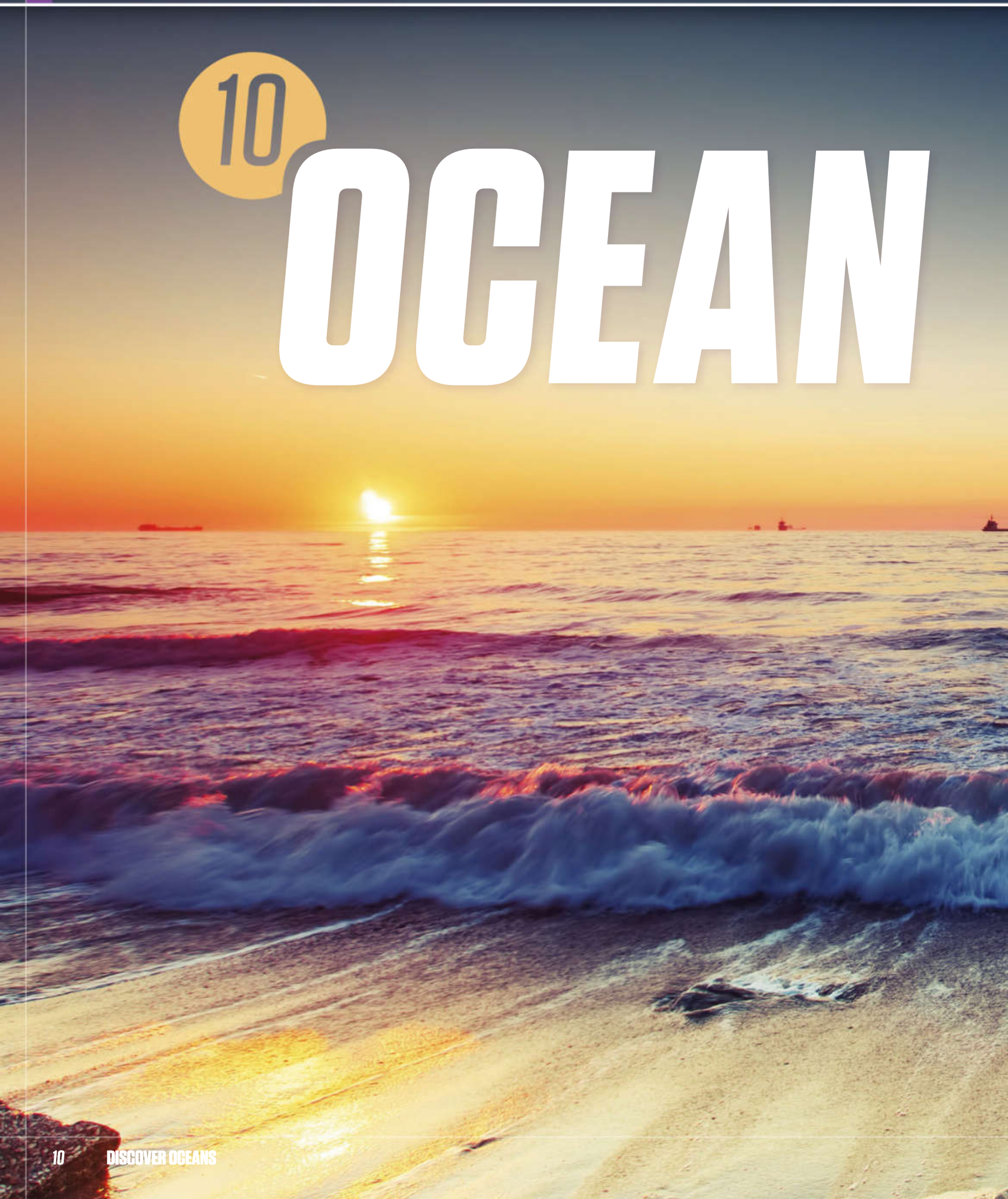


10 OCEAN

FACTS

A round-trip of geology and plant life native to the Earth's oceans

WORDS BY **TIM HARDWICK**

RANDOM MATTER

97% of the Earth's water is in the oceans

Around 2% is frozen in ice caps and glaciers. Less than 0.3% is carried in the atmosphere in clouds, rain and snow

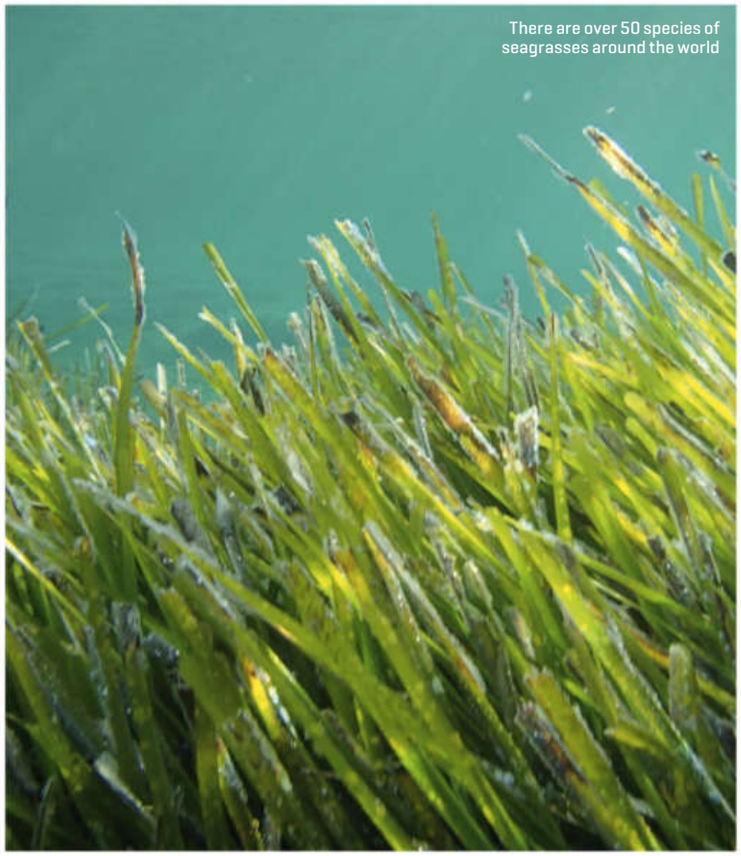
10 SEAGRASSES

Understated but vital to a range of fish, birds and marine life

Seaweed and other algae aren't the only vegetation to be found in the oceans. Seagrasses are flowering marine plants of which there are thought to be around 50 species, most of them concentrated in warmer waters like the tropics. They typically have long, thin leaves containing air channels. These leaves grow from 'rhizomes' that establish roots in the seabed, securing the plant in the flowing water and stabilising the sediment below. Seagrasses like shallow waters and form thick beds, making them important habitats for aquatic life.

Marine life known to directly feed on seagrasses includes green turtles, manatees, fish, geese, swans, sea urchins and crabs. Seagrasses can grow in isolated patches or form carpet-like coverings spread over miles. They also work as a cushion against currents, although the more volatile the water, the less likely it is that seagrasses will thrive.

SEAGRASSES LIKE SHALLOW WATERS AND FORM THICK BEDS, MAKING THEM IMPORTANT HABITATS FOR AQUATIC LIFE



There are over 50 species of seagrasses around the world

ABOVE Mangroves come in many forms including shrubs and trees. Whatever their size, they have adapted to low-oxygen conditions of waterlogged terrain

MANGROVES CAN SURVIVE IN HIGHLY SALINATED WATER. THIS IS ACHIEVED THROUGH ROOTS THAT FILTER OUT SALT

9 MANGROVES

Algae, sponges and invertebrates all benefit from the humble mangrove

Many tropical and sub-tropical shores are home to a unique group of large shrub-like plants called mangroves. These plants tend to form dense, submerged 'forests' along shorelines, thanks to their adaptive ability to survive in sea water that's too salty for other land plants to live in. Mangroves achieve this through specialised roots that filter out salt and leaves that excrete it into the water.

Mangroves make up the flora of coral reefs, where they enhance the ecological diversity. Their complex root systems serve as nursery habitats for marine life as well as providing the substrate for algae, sponges and other invertebrate animals. And like seagrasses, mangroves are instrumental in building sediments along shorelines and lagoons.

It might be hard to imagine their breadth if you're reading this in northern Europe, but just imagine the following… The nation of Belize features the highest overall percentage of forest cover of any of the Central American countries. This density's reflected in its mangrove cover. A 2010 satellite-based study of Belize's mangroves by the World Wildlife Fund observed that mangrove spread over 184,548 acres, which is the equivalent of 3.4% of Belize's territory.

8 MARINE FUNGI

One of the world's oldest life forms could be a source of medicine

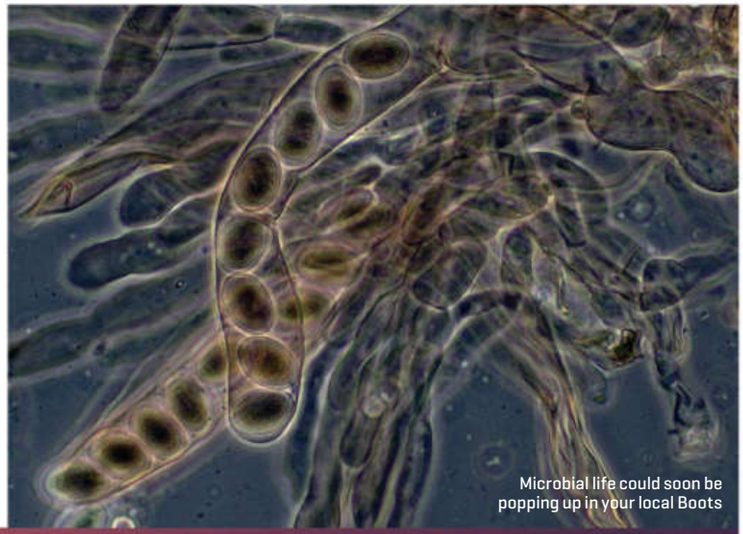
Beneath the ocean floor lives a largely unstudied community of microbial life that scientists have dubbed the 'dark biosphere' and are now only just beginning to explore. One type of life that researchers are particularly excited about is ancient marine fungi because of its genetic variety and potential for developing new medicines and drugs.

"Fungi can produce interesting natural compounds, some of which are antibiotics," says microbiologist William Orsi of the Oceanographic Institution in Massachusetts. "Deep biosphere fungi are an untapped resource by the pharmaceutical industry."

Orsi has analysed sediment from as deep as 127m beneath the sea floor, retrieved from ocean basins around the world. There he has discovered a diverse fungi community living in the mud, some of which is 2.7 million years old. The oldest fungi living in the sediment of the Pacific Ocean has been found to correlate closely with the amount of organic carbon sediments present, which indicates their role in carbon recycling in the sub-surface ecosystem. That's not so surprising if you consider that some fungi species have the natural ability to break down industrial toxins, and even crude oil components that have been released into the ocean.

Not all seafaring fungi is so eco-friendly, however. For instance, the fungus known to cause dandruff and eczema in humans has been found throughout the ocean, but largely favours coral reefs where it has been implicated in disease and ecological decline.

FUNGI CAN PRODUCE NATURAL COMPOUNDS, SOME OF WHICH ARE ANTIBIOTICS. THEY'RE AN UNTAPPED PHARMACEUTICAL RESOURCE



Microbial life could soon be popping up in your local Boots

IMAGE © US COAST GUARD

7 MARIANA TRENCH

Hop aboard and visit the deepest recess in the world's oceans…

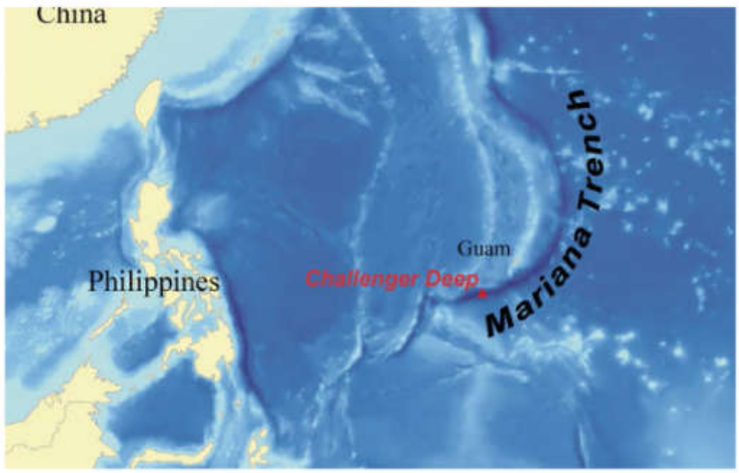


IMAGE © MARK LEEN

THE 1,500-MILE-LONG TRENCH IS HOME TO THE CHALLENGER DEEP, AN AREA THOUGHT TO DROP 36,000 FEET INTO EARTH

If you want to visit the deepest spot in the ocean, your first port of call should be the Western Pacific, just east of the Mariana Islands near Guam, where the Mariana Trench lies. Aside from its many active hydrothermal vents and mud volcanoes, the 1,500-mile-long trench is home to the Challenger Deep, an area thought to dip 36,000ft into the Earth. Compare that to Mount Everest, which stands at 29,000 feet, and you begin to get an idea of the sheer depths involved.

The Mariana Trench is the result of a subduction event in which two gigantic slabs of the Earth's crust collided, forcing one layer underneath the other. The deep trench marks the historic spot where the two plates would have met. But the immense water pressure at the floor of the trench ensures that you won't be visiting those depths soon – at more than eight tons per square inch, it would be the equivalent of having 50 jumbo jets piled on top of you.

Yet despite the crushing pressure, life thrives in the Challenger Deep. Scientists have dropped special canisters to the bottom to collect sediment and identified more than 200 microorganisms living there.

The Mariana Trench lies east of the island of Guam

Amazingly, the Mariana Trench can't lay claim to being the closest place to the centre of the Earth. That's because the planet bulges at the Equator, making parts of the Arctic Ocean seabed closer to the core than even the Challenger Deep.

RANDOM MATTER

The Mid-Ocean Ridge stretches for 40,000km

It's four times longer than the Andes, Rocky Mountains and Himalayas combined

6 THE FROZEN OCEAN

Welcome to the Arctic – the smallest and shallowest of the world's oceans

ABOVE Sea ice means the Arctic is the least-explored ocean in the world

Covering an area of about 5,427,000 square miles, the Arctic Ocean is about the size of Russia, and yet the smallest and shallowest of the world's five major oceanic divisions. It's also one of the least explored, primarily because ice partly covers it throughout the year. It's surrounded by the land masses of Eurasia, North America, Greenland and several islands, while an underwater ridge divides it into two basins, which are further subdivided by ridges.

The Arctic Ocean's surface temperature and salinity varies seasonally. Salt lowers the freezing temperature of seawater to -2°C. Despite this, when the atmospheric temperature drops in the Arctic, a thick layer of seawater begins to freeze. Tiny ice needles start to form, creating a salt-free solution called 'frail ice'. As the temperature continues to fall, the frail ice thickens and traps pockets of salty water in its layers. By force of gravity the heavier brine eventually moves down into the lower layers, leaving the upper layers to become more dense and gradually form pack ice.

In the summer, the ice melts and the surface cover can be reduced to half of what it was. Phytoplankton (see fact five) thrives during this time, when the sun is out day and night, but struggles to survive in the dark days of winter. Climate change is blamed for the increasing loss of sea ice throughout the Arctic Ocean, as well as the melting of the Greenland ice sheet.

CLIMATE CHANGE IS BLAMED FOR THE INCREASING LOSS OF SEA ICE

5 PHYTOPLANKTON

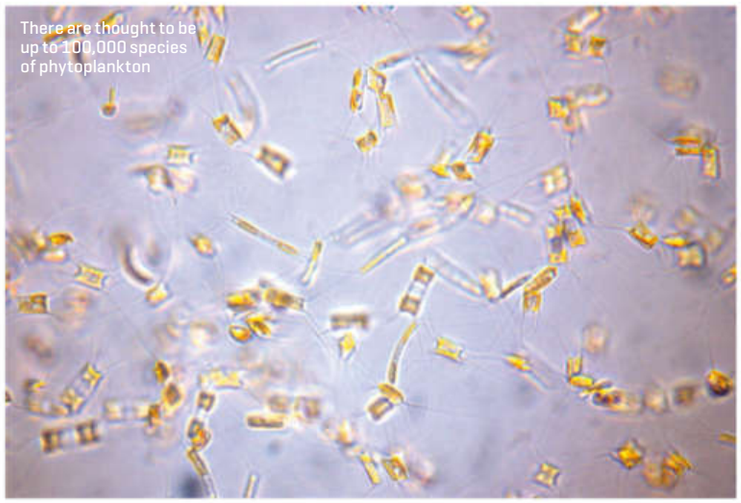
These single-celled plants are one of the most vital members of the food chain

What makes the oceans' ecology so intriguing is the amount of hidden life within – not just in its depths but dispersed across every level of the water column. One of the most important aspects of its rich biodiversity is the presence of micro-algae called phytoplankton, which form an essential component of the food chain. These single-celled plants not only provide nourishment to many marine animals, but also help to regulate the amount of carbon in the atmosphere, and are responsible for about the same amount of photosynthesis each year as all the plants on land combined.

Diatoms and dinoflagellata make up the two main types of the larger phytoplankton species. The pillbox-shaped cell walls of diatoms are composed of silica and house two valves (frustules) on top of each other. They can be found singly or in chains and reproduce by dividing in half, making each generation smaller than the last. There are thought to be as many as 100,000 species inhabiting the oceans.

The extravagant-sounding dinoflagellata get their name because of their whip-like appendages (flagella) that enable them to move about in the water. Their protective walls are cellulose rather than silica and, unlike diatoms, they don't form chains. Some species even produce toxins that, when released in large blooms, can cause 'red tides' and are poisonous to other marine life. Perhaps the most fascinating of dinoflagellata, though, are the bioluminescent kind, which in sufficient numbers can light up the ocean's waves in the nighttime.

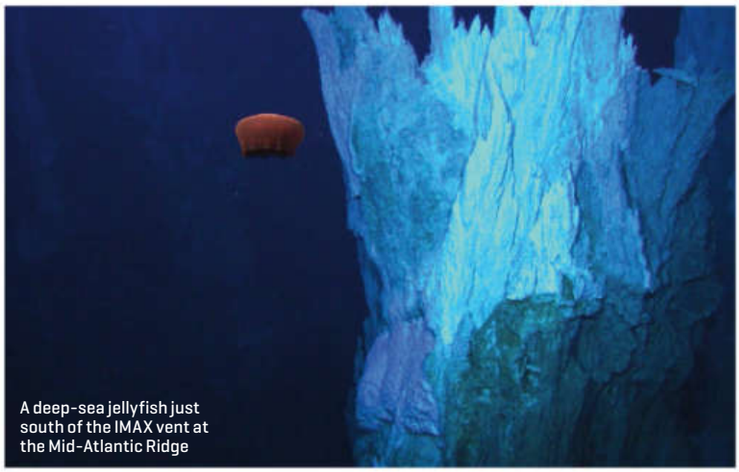
DINOFLAGELLATA GET THEIR NAME BECAUSE OF THEIR WHIP-LIKE APPENDAGES THAT PROPEL THEM THROUGH THE WATER



There are thought to be up to 100,000 species of phytoplankton

4 THE MID-ATLANTIC RIDGE

Formed from a rift that separates the North America and Eurasian plates



A deep-sea jellyfish just south of the IMAX vent at the Mid-Atlantic Ridge

THE ATLANTIC OCEAN IS MOVING AWAY FROM THE MID-ATLANTIC RIDGE AT A RATE OF AROUND 0.02M EACH YEAR

If ever you were under the illusion that the ocean seabed is just one long featureless plain with the odd cavern here and there, then reading about the longest underwater rift valley on Earth will change your mind. It's called the Mid-Atlantic Ridge and runs from Iceland to Antarctica, formed by an oceanic rift that separates the North American Plate from the Eurasian Plate via a trench over 25,000ft deep. The ridge was discovered in 1872 during a telegraph cable-laying expedition on the HMS Challenger. But it wasn't until 1925 that the ridge's existence was confirmed by sonar and found to extend all the way into the Indian Ocean.

The ridge sits atop the highest point of the mid-Atlantic rise – a bulge in the ocean floor where heat convection forces the oceanic crust upwards as the two tectonic plates move away from each other. As the Earth's mantle rises toward the surface below the ridge, pressure is lowered and the surface hot rock starts to melt. This is how a new ocean seabed is formed and the ocean basin widens, in a process known as sea-floor spreading. (In fact it was the discovery of the ridge that led the theory to gain acceptance.)

The Atlantic Ocean is moving away from the Mid-Atlantic Ridge at a rate of around 0.02m each year. In other words, North America and Europe are moving away from each other at about the same rate it takes for your fingernails to grow.

ABOVE The Mid-Atlantic Ridge pokes its head above water on the island of Iceland

3 THE CONTINENTAL SHELF

Delve deeper into the oceans and you find a world of canyons and channels

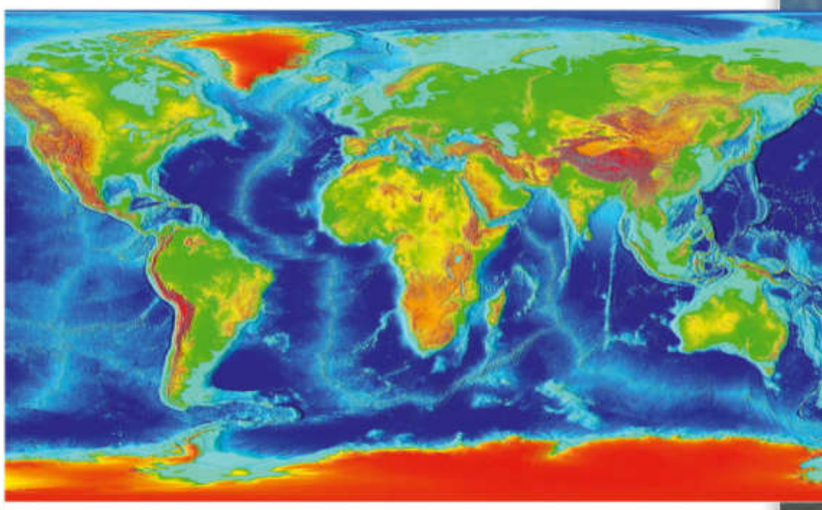
Looking at a geographical map of the Earth, you'd be forgiven for thinking that the continents end where the land meets the sea. However, most continents extend much further beneath the ocean in an extended perimeter called the continental shelf. Around the British Isles, for instance, continental shelf seas cover a total area that is several times that of the UK.

Indeed, these underwater terraces account for around 7% of the world's oceans. These shallow regions feature a varied seascape that includes canyons and channels, and are typically home to a rich biodiversity.

Taken together, the ocean's shelf areas average approximately 200ft deep, making them easily penetrated by sunlight and home to a vast ecology of marine life. Researchers estimate that about 15% of the ocean's plant growth occurs in shelf areas. The 'shelf break', meanwhile, is the steep slope where the continental shelf ends and the 'abyssal deep' begins, which has been described as the 'desert of the sea'.

The average width of continental shelves is said to be about 40 miles. At 932 miles wide, the Siberian shelf in the Arctic Ocean is the largest of them all. Shelves are also found in the South China Sea, the North Sea and the Persian Gulf. By contrast, some geographical areas, such as the coast of Chile and the west coast of Sumatra, do not have a continental shelf because they lie in zones where tectonic plates meet.

AT 932 MILES WIDE, THE SIBERIAN SHELF IN THE ARCTIC OCEAN IS THE LARGEST CONTINENTAL SHELF ON THE PLANET



BELOW The light-blue hue around the continents is the continental shelf

Mussels bed in at a chemosynthetic cold seep in the Gulf of Mexico.

IMAGE © EXPEDITION TO THE DEEP SLOPE 2007, NOAA-OE.

2 COLD SEEPS

Cold seeps are the calmer, more sedate version of hydrothermal vents, but still fuel much life

IMAGE © NOAA OKEANOS EXPLORER PROGRAM

ABOVE Cold seeps emit sulphide, methane and hydrocarbon-rich liquid into their surroundings. This provides the perfect breeding ground for many communities

A cold seep is a deep-sea vent that isn't super-heated but still emits sulphide, methane and hydrocarbon-rich liquid into the surrounding water. Dr Charles Paul is credited with their discovery in 1984, when he found them at a depth of 3,200m in the Gulf of Mexico. Since then, cold seeps have been discovered in the Sea of Japan at a depth of 6,500m, as well as in the waters off the Alaskan coast.

Unlike hydrothermal vents, cold seeps release gases and fluid gradually, enabling reactions between the seawater and methane to form carbonate rock formations and reefs over time. Entire communities of simple organisms gather around the outlets of the cool vents and generally live longer than those at heated vents because of the relative stability of resources. Giant tube worms hanging out here can live as long as 250 years, but cold seeps are perhaps best known for the formation of dense mussel beds. Many of the creatures, like the mussels, form symbiotic relationships with microorganisms that process the sulphides and methane into hydrocarbons, offering a safe haven for the bacteria in exchange.

Those giant tube worms, however, begin to disappear when the cold seeps become inactive, paving the way for corals to settle on the now exposed carbonate substrate.

Cold seeps aren't just notable features of the deep ocean for the ecosystems they host; they could also prove valuable new sources of energy. Gas hydrates store large amounts of chemically bound energy and can be found at seeps where the water has become saturated with methane gas, and many countries, including the USA, Japan, South Korea, India and China, are currently exploring safe ways to harvest them for fuel.

MANY COUNTRIES ARE EXPLORING SAFE WAYS TO HARVEST COLD SEEPS' METHANE FOR FUEL

1 HYDROTHERMAL VENTS

Submarine vents are home to a variety of complex organisms

HYDROTHERMAL VENTS ARE FOUND IN VOLCANICALLY ACTIVE AREAS WHERE MAGMA SITS CLOSE TO THE CRUST

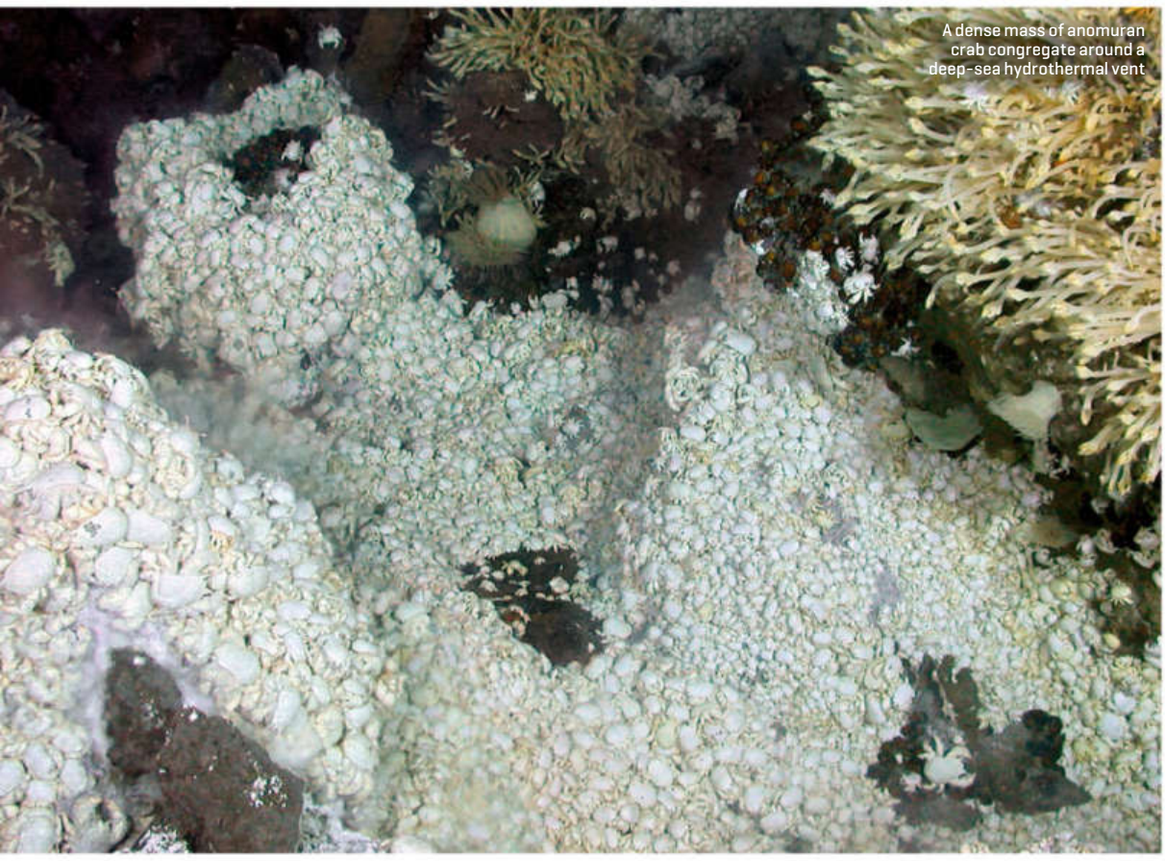
Submarine hydrothermal vents, also known as black smokers, are fractures or cracks in the Earth's surface, which spew out geothermally heated water. Typically, hydrothermal vents are found in volcanically active areas where hot magma is close to the surface crust. On land, these vents look like springs emitting boiling water or steam and gas. Underwater, however, it's a different story. The vents are usually hundreds of metres wide and the water never boils due to the extreme pressures that it's exposed to at depth.

Submarine vents can form chimney stack-like structures on the ocean floor – crystallisations of the many dissolved minerals (such as sulphide) contained within the heated water. The black colour is a result of the precipitation of minerals when the cold ocean water and the super-heated water collide. Black smokers can be found in the Pacific and Atlantic Oceans at a depth of 2,100m.

Perhaps surprisingly, the areas around these black smokers are home to a variety of complex organisms, which feed off chemicals that are dissolved in the process of fluid emanation. Rather than rely on photosynthesis to survive, which would be impossible because sunlight cannot penetrate the water at this depth, the organisms use chemosynthesis to convert sulphuric compounds into energy.

In 2000, scientists discovered a series of hydrothermal vents made from calcium carbonate in an area of the mid-Atlantic Ocean now known as the Lost City. About 30 of these chimney-like vents are situated around a mountain called the Atlantis Mass, where hydrogen-rich fluids and methane are produced by reactions between seawater and the Earth's upper mantle. The vents are much older than black smokers and differ in that they don't release much carbon dioxide, hydrogen sulphide or metals into the water, yet are home to microorganisms and invertebrates.

Intriguingly for scientists, the Lost City offers an Earth-based model of an ecosystem driven by abiotic methane and hydrogen – the kind of environment that researchers think may sustain life on other planets.



A dense mass of anomuran crab congregate around a deep-sea hydrothermal vent

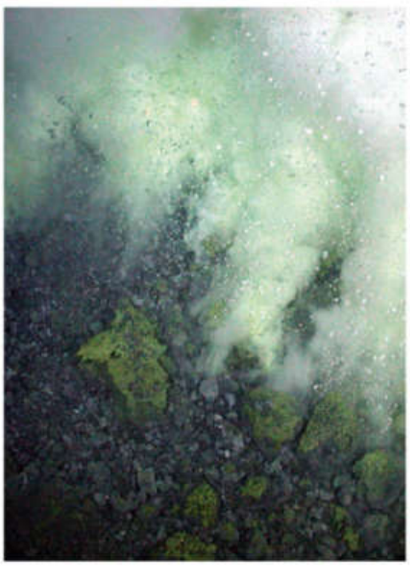


IMAGE © SUBMARINE ROF 2006, NOAA VENTS PROGRAM

ABOVE Organisms use chemosynthesis to convert sulphuric compounds into energy

Tim Hardwick
Science writer
+ Tim is a freelance writer whose interests include science, technology and evolutionary biology. He also has a background in literary history. *@markustimwick*

RANDOM MATTER

Ancient Earth had a different atmosphere than today

Gaseous elements included methane (CH_3), ammonia (NH_3), water vapour (H_2O) and carbon dioxide (CO_2)

How the oceans were formed...

Over 3.8 billion years ago the Earth was a hellish, scorched landscape littered with volcanic activity – so how did it acquire a series of oceans that cover two thirds of its surface?

WORDS BY **DOM RESEIGH-LINCOLN**

For millions of years, our five oceans have covered over 70% of the world's surface in water. Rich in biodiversity, these deep blue depths aren't just a vital part of our planet's existence – they also played a central role during the very genesis of terrestrial life. But despite their considerable presence, the manner in which they were created remains something of a mystery. How did water form on a world that was once defined by volcanic eruptions and an inhospitable atmosphere? How long did this process take? And what effect did the formation of continents have on young oceans all those years ago?

THE VIOLENT EARTH

The oceans of Earth formed roughly 3.8 billion years ago at the end of an ancient Earth era known as the Hadean Eon. During this 600-million year-long period, our planet was in a violent state of flux, constantly bombarded by asteroid impacts and with an atmospheric temperature between 30°C and 50°C. Yet it was here, among the volcanic eruptions and an air thick with carbon dioxide, that the very beginnings of our oceans began to take shape.

So did water exist on Earth in one form or another in this period? In short, yes, but due to the extreme temperatures caused by the planet's violent volcanic activity, such water was unable to retain a liquid form and instead existed as crystals within minerals that were superheated by volcanic activity and shot into the atmosphere as a form of vapour. Some of these crystals would have been present during the Earth's earliest formation, but there's strong evidence to suggest these reserves were bolstered by reserves from other planetary bodies impacting the planet's surface.

"In the age of the primordial accreting Earth, minute traces of water were bound in minerals and in things like hydrocarbons," says professor Chris MacLeod, an Earth and Ocean Sciences Lecturer at the University of Cardiff. "Much of it would have been released from solid mineral phases as the Earth heated up, from collisional energy and radioactive decay, and from volcanic eruptions due to melting of the planet's mantle. So, in effect, the Earth and the early oceans effectively grew together from an early stage."

There's also another paradox to consider in the form of the planet's atmosphere. Around 4 billion years ago the Sun wasn't the intense mass of irradiated energy it is today; in fact, it's theorised the star was far fainter in its infancy at around 70 percent of its current output.

So why didn't the Earth descend into a premature ice age due to the lack of heat and luminosity? The answer lies in the Earth's atmosphere at that time. It's believed to have been thick and dense with high concentrations of methane and greenhouse gases. The vapour produced by the volatile eruptions on the surface would be retained in the clouds, which would have eventually been returned to the earth in an early, highly acidic form of rain. This atmosphere would have also helped keep the planet warm and ensure the slowly forming oceans remained liquid in form. But what was

When the conditions were right, it rained for centuries

But the oceans took time to rise because of large cracks in the Earth left by continued tectonic shifting

WHILE IT'S HARD TO PIN DOWN AN EXACT DATE THAT THE OCEANS BEGAN TO FORM, GEOLOGISTS BELIEVE IT HAPPENED ROUGHLY 3.8 BILLION YEARS AGO

OCEAN FORMATION: THE THEORIES

As well as the meteorite theory [see body copy], further ideas abound

1 THERE ARE VAST ANCIENT UNDERGROUND OCEANS

+ According to a paper presented by researchers at Ohio State University, rocks hundreds of feet beneath the surface contain large amounts of water. Most of this water was sequestered via a mixture of heavy water delivered by comets and moisture taken from solar dust clouds. Such water is contained as hydrogen and oxygen atoms in crystal defects and minerals.

2 PRIMORDIAL COOLING

+ One theory states that liquid water could have existed once the planet's fiery temperature dropped sufficiently. Once the global temperature of the primordial Earth had dropped below 100°C, these deposits condensed into rain and soaked into the Earth, creating the hydrologic cycle we know today.

3 VOLCANIC ACTIVITY

+ Another theory, and one that ties into the concept of primordial cooling, relates to terrestrial water deposits finding their origins in the prevalent volcanic activity on Earth billions of years ago. In this instance, water vapour is expelled through volcanic eruptions, which eventually form moisture clouds in the atmosphere.

4 CLOUDS OF GAS AND DUST BIRTHED OUR OCEANS

+ The most popular and agreed upon theory relates to the process of water deposits contained with clouds of gas and dust – the common byproduct of the Big Bang and the universe's violent early nature. These deposits became trapped in porous rock deep inside the fiery heart of the young Earth, which was then expelled as steam, which in turn formed clouds of moisture.

Oceans were divided by shifting tectonic plates

Around 300 million years ago, the formation of Pangaea means the oceans were united as a single body of water

the catalyst that created liquid water on Earth…?

THE BIG THEORIES

There are numerous theories relating to this period, but the main arguments fall into three main schools of thought. The first purports that the seas are the product of clouds of dust and gas released by the formation of the universe, which brought considerable amounts of water vapour to our world. The second and third centre around ice deposited deep in the Earth's mantle by high numbers of comet and meteorite impacts.

So which one of these hypotheses holds, if you'll excuse the pun, the most water? "There are plenty of theories relating to the origins of the Earth's oceans, but there's one I can debunk for you straight away," says MacLeod. "Comets didn't play a major factor in contributing large amounts of liquid water to the seas, mainly because their deuterium-hydrogen (D/H) ratio is high. This leads to something known as 'heavy water', which isn't prevalent in our oceans."

Heavy water is defined by high levels of deuterium, caused by bombardment from cosmic rays. It's found on icy comets that have been hurtling through space for millions of years. "Comets may have made a small contribution, but the most likely answer lies in a mix of impacts from carbonaceous chondrite meteorites and the influence of primordial dust and gas clouds," adds MacLeod.

Those clouds were one of the most potent blocks in the formation of the universe – pockets of ice, minerals and other detritus that had been vapourised into thick solar clouds thanks to the birth of new stars.

The concept of the Earth's oceans being filled by vapourised ice also supports the theory that a significant proportion – around 30-50% – of the ancient Earth's seas were actually older than the Sun itself.

"When a star lights up, it breaks down water into oxygen and hydrogen, lowering the D/H ratio," continues MacLeod. "This is why comets formed far away from the Sun have high (closer to interstellar) D/H compared to those on Earth. However, Earth's D/H, although lower than comets, is still higher than predicted for water formed close to the Sun. Hence, the idea that a proportion of Earth's water is D-enriched interstellar material that survived the Sun's ignition."

So what of those carbonaceous meteorites? Unlike other forms of meteorite, CM and CI variants are known for their high concentrations of water – between 3% and 22% – and it's these bodies that are believed to have struck the Earth during a period known as the 'Late Heavy Bombardment' (a lunar cataclysm that took place 4.1 to 3.8 billion years ago). Such consistent bombardment would have added to Earth's overall accretion and supplemented the increased presence of water-rich minerals.

ABOVE As destructive as they seem, volcanoes played an important part in the creation of an atmosphere that could sustain liquid water while maintaining a viable global temperature

THE OCEANS GROW

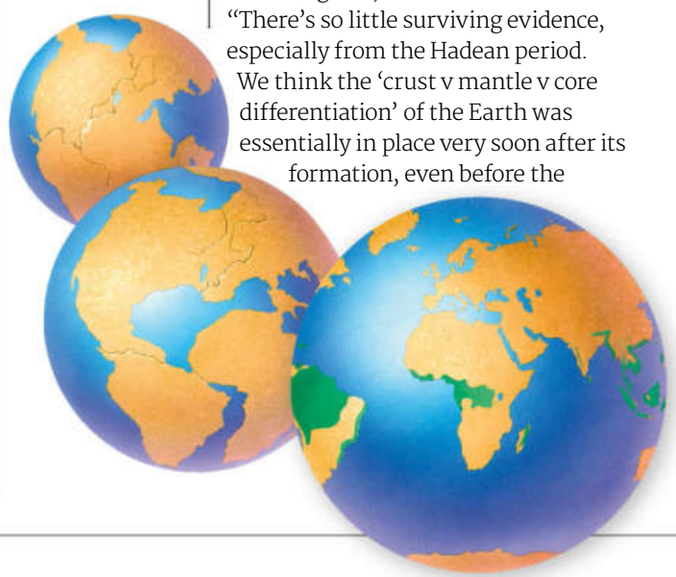
That dense atmosphere above ancient Earth comprised mainly methane (CH_3), ammonia (NH_3), carbon dioxide (CO_2) and water vapour (H_2O). As global temperatures cooled below 100°C, these elements began to condense into precipitation which slowly began falling into the lowest-lying lands. Many of these areas would have poured into volcanic rifts to create subduction, leading to plumes of water vapour and mineral rich deposits shooting back into the atmosphere.

As water entered the oceans from the atmosphere, it brought with it dissolved gasses that were released from mantle by volcanic activity and geysers. Water also flowed as run-off from the surrounding lands, which provided minerals from rocks on the Earth's surface. These dissolved minerals were vital in enriching these early waters, including the addition of salts (a staple of modern seawater).

The geochemical cycles that define our oceans found their beginnings here, with minerals and chemicals entering and evaporating from the waters in a burgeoning system that slowly built these individual bodies of water into huge oceans.

The question is, how long did it take until these large areas of rainwater and run-off had transformed into daunting seas? "Unfortunately, we don't have very much to go on," comments MacLeod. "There's so little surviving evidence, especially from the Hadean period. We think the 'crust v mantle v core differentiation' of the Earth was essentially in place very soon after its formation, even before the

BELOW Pangaea, the supercontinent, formed around 300 million years ago when major continental plates collided to create one giant land mass and one colossal ocean



Comets probably helped to fill our oceans

While it's unlikely they were the main source, some scientists suggest they contributed up to 20% of the oceans

Q&A PROFESSOR CHRIS MACLEOD

Professor, School of Earth and Ocean Sciences, Cardiff University

There's a geological distinction between continental landscapes and those found beneath oceans. Do these distinctions define where the early oceans formed?

It's important to note that the present configuration is geologically very recent. The current 6-7km-thick volcanic ocean crust formed by 'seafloor spreading' less than 180 million years ago compares to the 35km-thick continents that formed up to 3.8 billion years ago. The continents have moved around the surface of the planet, colliding or being ripped apart through time, changing configuration many times over. Occasional traces of former ocean crust are preserved along major fault zones. These remnants are called 'ophiolites' and are found in places such as Cyprus and Oman.

Were geochemical cycles (like gas-water exchange) present at this early stage or did they develop as the oceans stabilised?

Some cycles were very different. One idea is that early oceans were very acidic, with dissolved iron from hydrothermal venting combining with oxygen released from blue-green algae to precipitate iron oxide particles. These settled onto the seafloor (also known as the 'mass rusting event'). There was eventually a tipping point (at 2.3Ga) in which enough free oxygen was generated for oceans to become permanently oxygenated. This was known as the 'great oxygenation event'.

Volcanic activity pumped out both heat and minerals that would serve as the building blocks of life

> "THE CONTINENTS HAVE MOVED AROUND THE SURFACE OF THE PLANET, COLLIDING OR BEING RIPPED APART THROUGH TIME"
>
> **Professor Chris Macleod** EARTH AND OCEAN SCIENCES, CARDIFF UNIVERSITY

collision with Theia at 4.533Ga ['Ga' is a bespoke term used in geology that's shorthand for 'billion years ago'] and subsequent crystallisation of the supposed global magma ocean." (The magma ocean is a fabled, yet-to-be scientifically proven sea of interconnected magma pockets that sit beneath the Earth's mantle.)

CONTINENTAL INFLUENCE

The birth and evolution of our oceans also owes much of its current form to the formation of our modern-day continents. The break up of the supercontinent Pangaea (a landmass formed from every continent we know today, which broke apart about 200 million years ago) created the continental configuration we inhabit in 2015, dividing the oceans into seven separate entities.

This break up also created much of the ocean/mid-ocean ridges and present plate boundaries. The ancient ocean that surrounded Pangaea, known as Panthalassa, would eventually be divided into the Pacific, Atlantic and Indian oceans.

"Through an analysis of seafloor magnetic anomaly patterns, we have a good understanding of how the continents have moved since the Mesozoic period [252 to 66 million years ago]," says MacLeod. "But before the Mesozoic things are more difficult, as we have less direct evidence. There's no ocean floor any older than this to analyse magnetic anomaly patterns. Nevertheless we have indirect evidence that the continents broke up and collided many more times throughout Earth's earlier history (the so-called 'Wilson Cycle')."

This process is how the Earth regulates its size in relation to the formation of a new crust (created by volcanic eruptions) and the destruction of older crusts (taken care of via subduction). This cycle is what shattered Pangaea and many geologists believe it will drive the continents together again, creating a unified superocean once more.

The oceans remain one of Earth's most fascinating and intriguing characteristics. Despite advances in marine and geological sciences, we're still only brushing the surface of what our oceans were like millions of years ago, and what they'll become in the eons to come. And while very little evidence remains to give us a definitive picture of oceanic formation from the Hadean Eon until now, scientists remain hopeful. Considering we've only explored around 10% of our oceans, there's still a chance that down in the deep sea lie the answers that will truly unravel the mysteries of our life-affirming oceans.

Dom Reseigh-Lincoln
Science journalist
+ Dom studied veterinary medicine at university before deciding to pursue his love of journalism. *@furianreseigh*

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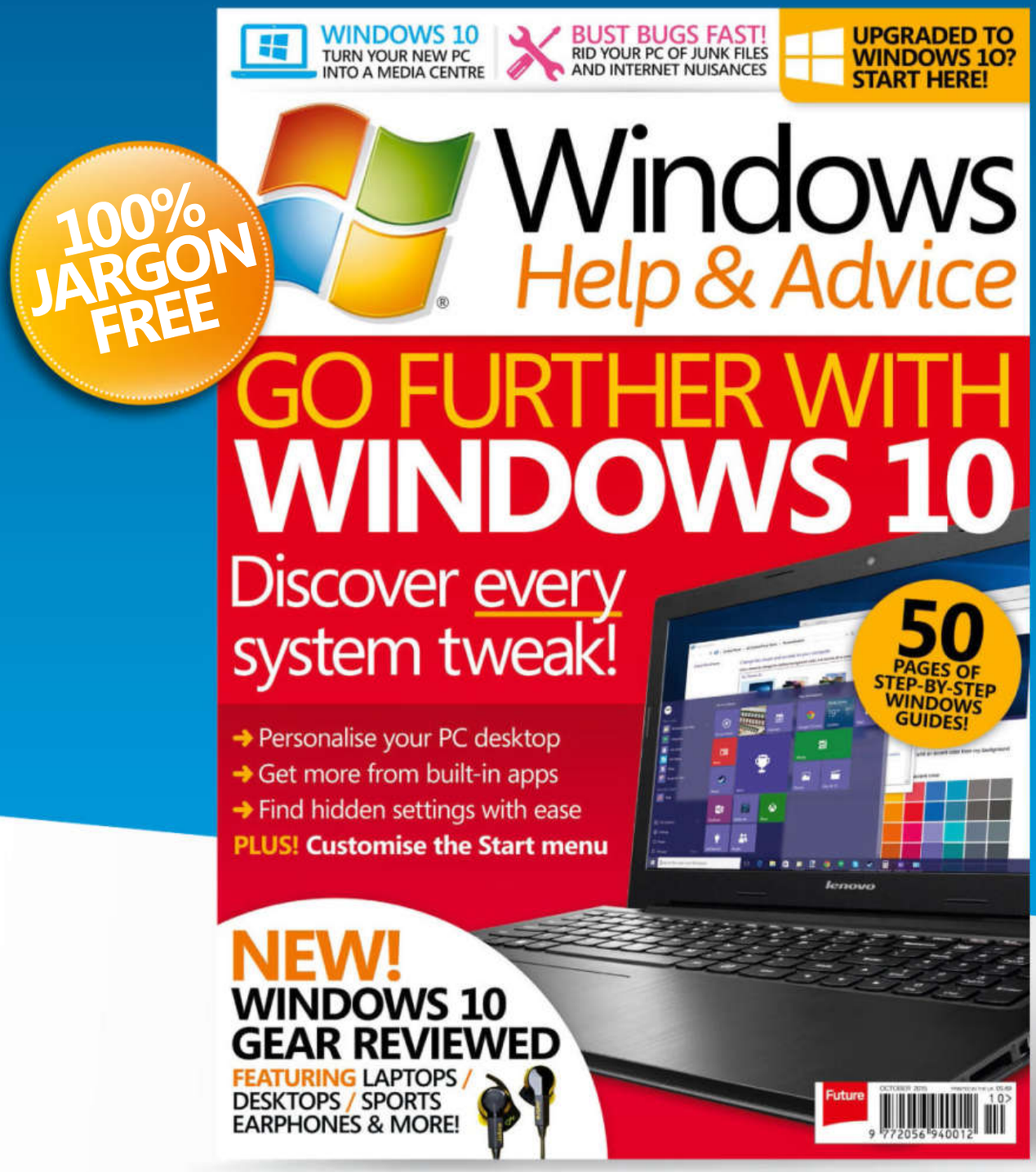

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HOW OCEANS AFFECT THE WEATHER

The sea doesn't just impact what's going on beneath the waves – it determines what happens above them, too

WORDS BY **Tim Hardwick**

The ocean covers 71% of the Earth's surface and, as a result, absorbs the majority of the sun's radiation. This makes it crucial to heating the planet. In fact, the top three metres of water in the ocean holds as much heat as the Earth's entire atmosphere. When this water is heated further, it evaporates into the air and increases temperature and humidity levels to form rain and storms, which are carried far and wide by the trade winds that encircle Earth.

But the ocean doesn't just store the sun's energy – it also cools and warms the surrounding atmosphere in various ways. For instance, when the air is cooler than the seawater, the ocean transfers heat to the lower atmosphere, which in turn becomes less dense as the molecules in the air are forced further apart. This results in a low-pressure air mass over that region of ocean, and because air flows from areas of higher pressure to areas of low pressure, winds are diverted towards the low-pressure area.

In some cases, fast-moving jet streams at high altitude are drawn into the lower region, creating conditions for the perfect storm. For example, when ocean water with a temperature of more than 26.5°C evaporates into the air, the warm air rises and cooler air descends, rotating around the low-pressure area as it does so. As the velocity of its spin increases, the wind grows in intensity, raising the likelihood of a hurricane.

The ocean doesn't just absorb and release the sun's radiation – it also acts like a massive conveyor belt by distributing this heat around the globe, accounting for its huge impact on Earth's weather patterns. Surface winds, temperature and salinity gradients combine to form these ocean currents, which are also influenced by the Earth's rotation, as well as tides caused by the gravitational effects of the Moon. These currents move along the surface of the ocean and in deep water (below 300m), circulating the planet in a 1,000-year cycle that significantly regulates its climate.

Without ocean currents, regional temperatures would be more extreme and make much less of the land habitable – the Earth's Equator would be unbearably hot.

That's not the only way the ocean protects our survival. It also helps to slow global warming by removing carbon dioxide from the atmosphere, thanks to tiny organisms in the water called phytoplankton (see page 34). These microbes use the sun's energy to make food through the process of photosynthesis, and if it weren't for these marine organisms, global warming could be occurring at a much faster pace than it already is.

Tim Hardwick
Science writer
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ABOVE **The ocean's heat-retaining properties have a huge influence on climates**

IMAGE © THINKSTOCK

There are around 1,500 active volcanoes above the sea

That figure's dwarfed by underwater volcanoes with around 10,000 active and inactive in the Pacific Ocean alone

UNDERWATER VOLCANOES

Over 75 percent of the world's volcanic activity takes place beneath the surface of our oceans... and it's these submerged peaks that have truly transformed the face of the Earth

WORDS BY **DOM RESEIGH-LINCOLN**

Volcanoes, be they continental (land-based) or submarine (underwater), are one of our planet's most fascinating natural wonders. Bursting from beneath the Earth's crust, they're a constant reminder of the tumultuous and superheated environment raging beneath our feet. Yet for all those images of volcanoes roaring into life on land, exploding with white-hot magma and plumes of ash, these violent acts only account for a small percentage of our volcano population. The biggest and most numerous candidates are instead beneath our seas, lurking in shallow waters and deep ocean depths.

These underwater vents and fissures account for a staggering 75% of our planet's annual magma output, with most of these volcanic wonders buried under an average of 2,600 miles of water. Around 5,000 known submarine volcanoes are currently in an active state, and these structures (which can range from 10m high to a staggering 3,500m from the seabed) play a vital if temperamental role in the fragile ecosystems of marine life. While many can provide the correct chemical conditions to support life, they can also wreck a previously established ecosystem, causing populations of fish and plankton to plummet as a result. They can also produce new lands, creating volcanic islands that quite literally rise from the depths. The islands of Hawaii, for instance, are the product of a submarine volcano eruption beneath the waves.

VOLCANO FORMATION

All volcanoes are formed by the shifting of tectonic plates in the lithosphere (the outermost layer of the Earth's composition). These plates – defined as continental or oceanic, depending on their location – can be affected by a variety of elements, including the rotation of the planet, gravitational pull and even the positioning of the Moon and the Sun.

Unlike their continental brethren, submarine volcanoes only exist along locations known as plate boundaries (these are essentially the point at which

AROUND 5,000 KNOWN SUBMARINE VOLCANOES ARE IN AN ACTIVE STATE. THESE STRUCTURES RANGE FROM 10M HIGH TO 3,500M

Surtsey Island near Iceland appeared in the '60s

It was 130m below the surface, but it's now 150m above the surface at its highest point

RANDOM MATTER

Volcanoes affect the climate

Eruptions can lead to warmer water and increased levels of CO_2, which can have serious effects on fragile ecosystems

THE BIGGEST UNDERWATER VOLCANOES

Five of the most awesome submarine volcanoes in the world

1 TAMU MASSIF

+ This subaquatic megavolcano is the largest on our planet. It's 650km wide and dwarfs that of Olympus Mons, the largest known volcano situated on Mars. Located in the Northwest Pacific, Tamu Massif has been inactive for 140 million years.

2 ADAMS SEAMOUNT

+ This submarine volcano is located on top of the Pitcairn Hotspot – a volcanic source that also created the Pitcairn Islands, along with another seamount, Bounty. Situated a good 56 miles from these islands, the Adams Seamount clocks in a staggering 3,500m tall.

3 MARSILI

+ One of many marine volcanoes located off Naples, Marsili is one of the world's largest. At more than 3,000m in height (and around 450m below the surface), it's also one of the most fascinating with geologists suggesting an eruption is imminent.

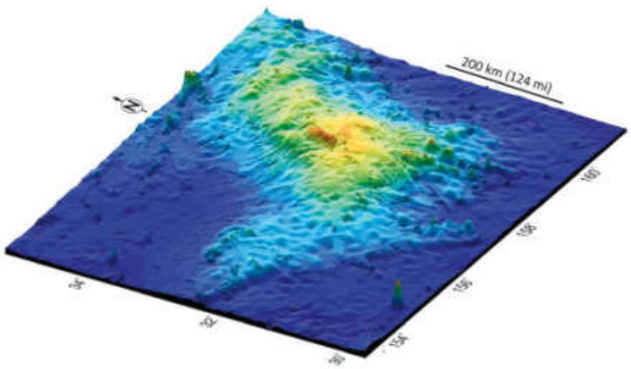
4 BOWIE SEAMOUNT

+ This large submarine volcano lies in the northeastern Pacific Ocean, situated around 110 miles from the coast of Haida Gwaii, British Columbia, Canada. Around 3,000m high, the Bowie Seamount is also categorized as a 'guyot' (it has a flat summit).

5 MOAI

+ With a height of 2,500m, the underwater volcano known as Moai can be found west of Eastern Island near the Pukao seamount. It's fairly young in terms of volcano development and was formed on the Easter hotspot in the last few hundred years.

LEFT Magma exists in the Earth's mantle, which transforms into lava when it erupts through the surface



BELOW A map of the ocean's floor, the 3D software showing the different gradients

IMAGE © PUBLIC DOMAIN

tectonic plates meet or separate). These boundaries come in three distinct varieties – convergent, divergent and transform – but submarine volcanoes only occur on boundaries that host convergent and divergent activity.

Ocean–ocean convergent boundaries are most commonly found further out to see in deep ocean environments and are the result of two subaquatic plates colliding. As the heavier of the two sinks beneath the lighter one, it creates a powerful process known as subduction. Within this new 'subduction zone', the descending heavier plate pushes into the hot mantle beneath it, causing magma to breach the lithosphere.

On the flipside, ocean–continental boundaries take place much further inland (and as such account for a majority of those submarine volcanoes found in shallower waters). In this scenario, the oceanic plate dives beneath the continental one. These events aren't isolated, either. Since they occur on colossal tectonic plates, these collisions create chains of volcanic activity (the Mid-Ocean Ridge being one such example).

CONTINENTAL VS OCEANIC

When it comes to the minutia of how oceanic and continental volcanoes erupt, the two processes are remarkably similar beneath the Earth's crust – it's how they differ above the surface that sets them apart. For instance, in colder climes both processes will still result in freshly erupted magma immediately cooling, a hard crust forming around it. As new magma flows out and into these pockets it creates a basaltic substance known as pillow lava. This kind of cooled lava is often a key building block for a volcano rising out of the ocean.

The three factors here are pressure, temperature and chemical compositions of the surrounding environment. When a volcano erupts in a continental setting, the magma that escapes cools over time, the process itself slowed by flammable oxygen in the air. As such, the typical building blocks of a growing volcano

On average, a volcano erupts 2,200m down

The water pressure at these depths means it's near impossible to detect them via heat

IMAGE © VOLKER STEGER/SCIENCE PHOTO LIBRARY

peak – layers of cooled lava – take a great deal of time to form.

In an oceanic environment, a volcano erupts in much different conditions. Whether in a shallow or deep ocean setting, the waters around the volcano are naturally cooler, which causes the erupting magma to cool almost immediately. With the pressure of the water, a submarine volcano enters a faster cycle of magma expulsion and cooling that'll push an oceanic volcano higher and higher. This rapid growth explains why oceanic volcanoes are often account for the biggest volcanoes on the planet.

WIDER OCEANIC EFFECTS

But what about their effect on the oceans? In the short term, not good. Submarine volcanoes are often the source of mantle-based gases such as carbon dioxide and sulfur dioxide, high heats and solutes. These react with the composition of seawater and often have a big impact, such as the volcanic eruption in the Canary Islands that crippled the local marine ecosystem, including destabilising the plankton population in that area.

Experts even believe subsurface eruptions are having a serious effect on global warming. Earlier in the year, researchers at the Lamond-Doherty Earth Observatory at Columbia University presented a report that suggests that the effects of submarine volcanoes isn't a localised issue, and that volcanoes are actively heating the oceans. "People have ignored sea-floor volcanoes on the basis that their influence is small, but that's because they're assumed to be in a steady state, which they're not," says Dr Mara Tolstoy, a marine geophysicist involved in the project. "They respond to both very large forces and to very small ones, and that tells us that we need to look at them much more closely."

Yet for those environments that play host to consistently active hydrothermal vents and volcanic openings, such pairings can create a positive symbiosis of sorts. Seawater that fills the cracks created by a volcanic eruption mix with the chemical composition within, which is then expelled as hydrothermal fluid. This mineral-rich fluid provides a perfect environment for bacteria and archaea that harvest the chemical energy. These waters, now heated beyond their normal temperature can now support far more diverse forms of life including tape worms, shrimp and even crabs. DS

Dom Reseigh-Lincoln
Science Writer
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DETECTING POTENTIAL DESTRUCTION

Four technological advancements that can accurately detect and measure seismic activity

COSPEC

+ An abbreviation for correlation spectrometer, this specialised device is used to measure gas deposits emitted from volcanoes both above and below the surface of the ocean. It was originally developed for measuring pollution coming out of factory smoke stacks.

VLF

+ VLF or Very Low Frequency is a method used by geologists and volcanologists to study the progress of magma beneath the crust of a volcano. VLF signals are bounded off these flows in order to determine how close a site is to eruption.

TILTMETERS

+ Tiltmeters are like a more complicated, and considerably more expensive, version of a carpenter's spirit level. Electrodes in a liquid solution detect the movement of an air bubble that reacts to volcano-related ground deformation.

CAMERAS/ MICROPHONES

+ With reduced visibility and audio, geologists and volcanologists have to rely on highly specialised surveillance gear to record the progress of a volcanic site before, during and after an eruption event.

IMAGE © BROKENSPHERE / WIKIMEDIA COMMONS

SCIENCESHOT

Stunning images from the Earth's oceans

THE OCEAN FLOOR

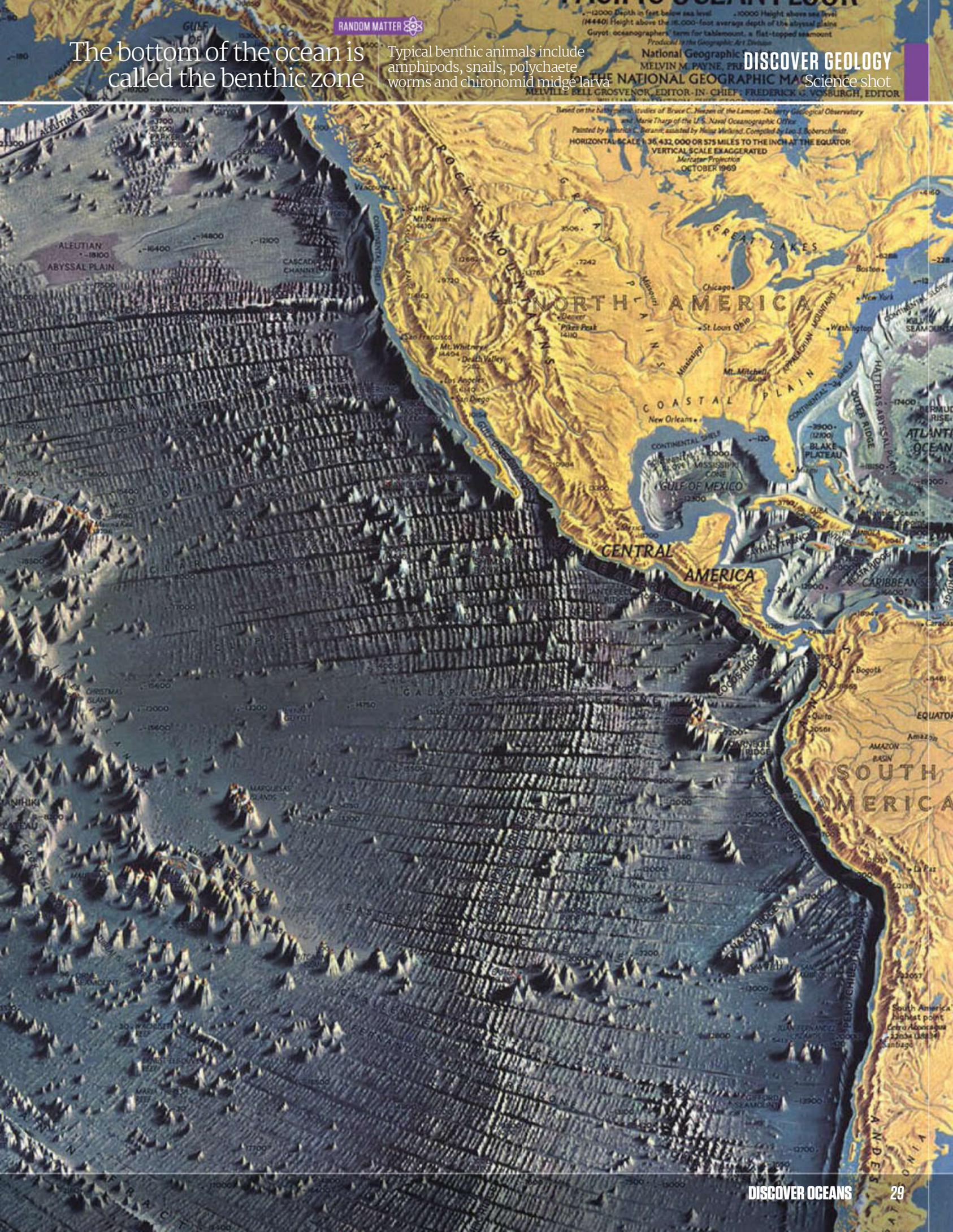
Beneath the waves lies a fascinating abyss, defined by the continental shelf and the deep abyss

PHOTO © MAPPERY.COM

With over four billion years of geological formation, the floors of our planet's many oceans are varied and fascinating. Most have the same composite structure, wrought from tectonic movement and sedimentary build-up, but the main areas are defined by their depth. Coastal descent transitions from the continental shelf to the continental slope, before a steep drop into the main seabed level – the abyssal plain. Usually found at depths between 3,000 and 9,000m, the abyssal plain accounts for over 50% of the ocean floor.

The bottom of the ocean is called the benthic zone

Typical benthic animals include amphipods, snails, polychaete worms and chironomid midge larva



A tsunami struck the east coast of Japan in 1700

Recent research suggests it could have stemmed from a massive earthquake in the northwest of America

Tsunami destruction

The many causes and effects of the most devastating ocean phenomenon known to man

WORDS BY **Tim Hardwick**

Tsunamis were virtually unknown in the public consciousness before Boxing Day 2004 when 230,000 people lost their lives in 14 different countries bordering the Indian Ocean. Yet tsunamis are nothing new. The first tsunami in recorded history happened back in 426BC off the coast of Greece, while geological evidence points to similar events occurring throughout the early life of the planet.

The term 'tsunami' is originally Japanese (its closest meaning in English being 'harbour wave') though it has been in English use for more than 100 years, ever since one hit the northeast coast of Hondo, Japan, in 1896. Since then, scientists have been busy uncovering the various causes of tsunamis in an effort to mitigate the damage they can have to the surrounding lands, their infrastructure and people.

In 2015 we have tsunami early warning centres positioned in every major ocean around the world, but the fact remains that their unpredictability and relative infrequency make tsunamis notoriously difficult to study. Each one is unique and often little is known in advance about where the worst waves will hit and how destructive they will be.

SEAQUAKE TSUNAMI

The most common cause of a tsunami (about 86% of all recorded incidents) is what's called a submarine or 'subduction' earthquake, more commonly known as 'seaquake'. These seaquakes result from the sudden movement of tectonic plates at 'subduction zones', where a denser plate is typically forced beneath a lesser one, or two slide alongside each other. If the quake is deep under the seafloor it may have no impact on the water above. Equally, if the seabed is displaced sidewards then typically no tsunami occurs.

But if the quake takes place at sea-floor level and the seabed is lifted

IN 2015 WE HAVE NUMEROUS TSUNAMI EARLY WARNING CENTRES POSITIONED IN EVERY MAJOR OCEAN AROUND THE WORLD

2004 witnessed the world's worst tsunami

More than 200,000 people lost their lives in the Indian Ocean, many of them washed out to sea

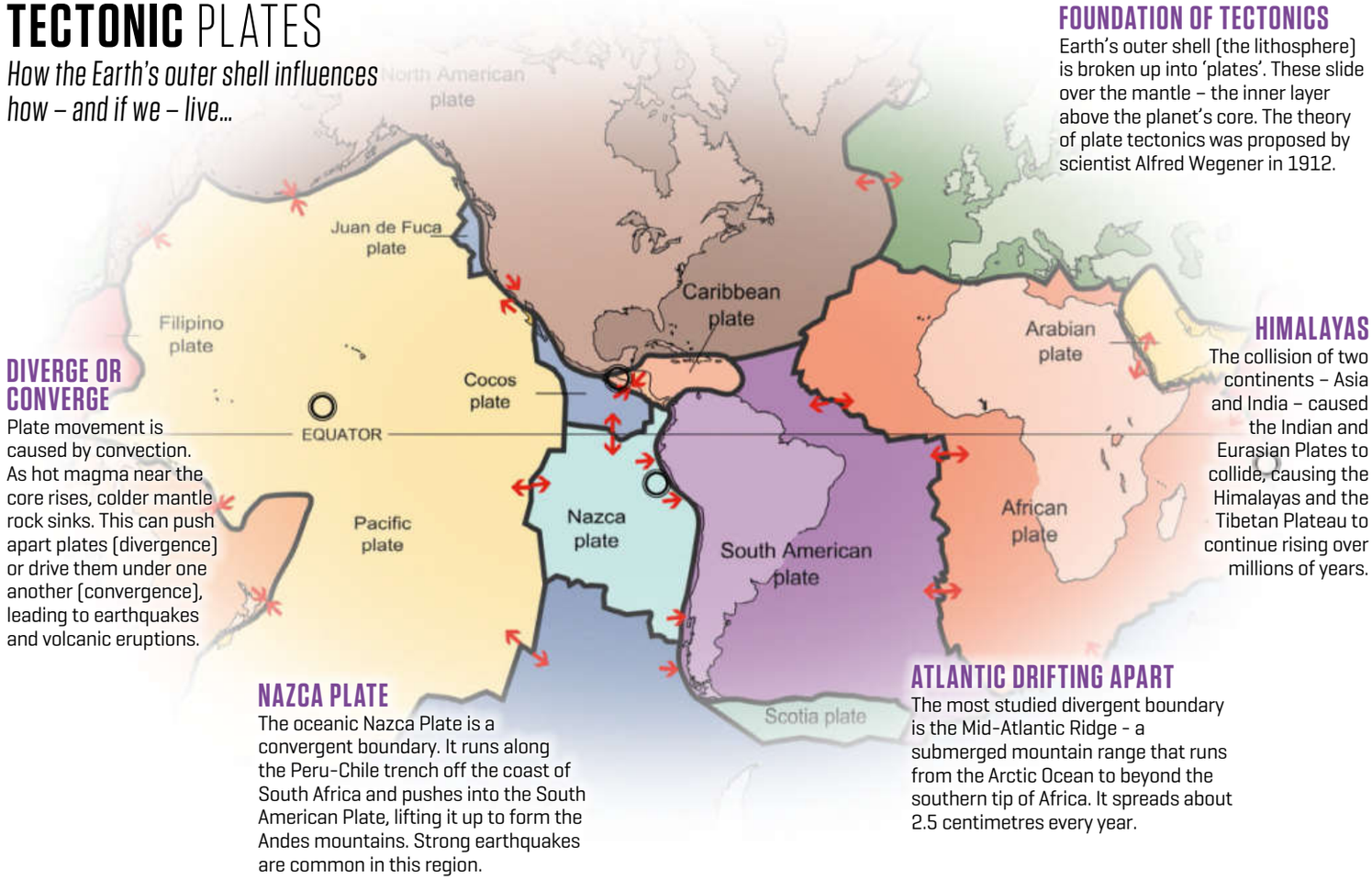
RANDOM MATTER

Coral reefs can act as tsunami barriers

Thick, sprawling underwater vegetation like mangrove and large coral reefs can reduce their destructive wave energy

TECTONIC PLATES

How the Earth's outer shell influences how – and if we – live...



FOUNDATION OF TECTONICS

Earth's outer shell (the lithosphere) is broken up into 'plates'. These slide over the mantle – the inner layer above the planet's core. The theory of plate tectonics was proposed by scientist Alfred Wegener in 1912.

DIVERGE OR CONVERGE

Plate movement is caused by convection. As hot magma near the core rises, colder mantle rock sinks. This can push apart plates (divergence) or drive them under one another (convergence), leading to earthquakes and volcanic eruptions.

HIMALAYAS

The collision of two continents – Asia and India – caused the Indian and Eurasian Plates to collide, causing the Himalayas and the Tibetan Plateau to continue rising over millions of years.

NAZCA PLATE

The oceanic Nazca Plate is a convergent boundary. It runs along the Peru-Chile trench off the coast of South Africa and pushes into the South American Plate, lifting it up to form the Andes mountains. Strong earthquakes are common in this region.

ATLANTIC DRIFTING APART

The most studied divergent boundary is the Mid-Atlantic Ridge - a submerged mountain range that runs from the Arctic Ocean to beyond the southern tip of Africa. It spreads about 2.5 centimetres every year.

ABOVE The 2011 Tohoku tsunami and earthquake killed nearly 16,000 people and displaced another 300,000

or lowered – and if the sudden jump in the movement of plates records at least a 7.0 on the Richter scale – then a tremendous wave of energy is transferred into the water column above and gravity forces the energy out horizontally at the surface. Indeed, the energy generated by a quake at the ocean floor may move away from the epicentre at speeds of up to 590mph. Amazingly the height of the tsunami wave may be less than one metre – but no less devastating.

LANDSLIDES AND VOLCANOES

Earthquakes aren't the only cause of tsunamis. They can be the result of underwater landslides – when steep slopes become loaded with too much sediment, or when changes in sea level cause sediments to become unstable. In such cases, the amount of sediment and the depth of the seafloor determine whether tsunamis occur. They are rare but not unheard of.

The most likely cause of the tsunami that devastated the northwest coast of Papua New Guinea in 1998 was an undersea landslide. On that occasion, three waves more than 7m high struck a six-mile stretch of coastline and three villages were completely swept away, killing over 2,000 people.

Volcanoes have also been known to cause catastrophic seismic waves. A land-based volcano may erupt to the point of collapse, dropping a cascade of ash and debris into the water. The sudden displacement of the water column results in waves, with further debris increasing the number of waves unleashed, as well as their amplitude. Such a scenario may seem far-fetched, but in 1883 around 36,500 people were killed by tsunamis in the South Java Sea when Indonesia's Krakatoa volcano erupted. Tsunamis can also be caused by underwater volcanoes – see page 24 to discover how.

METEOR IMPACT

Perhaps the rarest trigger of a tsunami is an asteroid collision. Scientists have found evidence suggesting such a cataclysm occurred some 3.5 billion years ago. It's believed the ensuing tsunami was of almost unimaginable size and swept around the planet several times, covering everything but the highest mountains. The continental coastlines were changed dramatically and almost all life on land was wiped out. This terrifying event is one of at

TSUNAMI TRACKING SYSTEM

Science's role in reducing the human cost

+ Since the Indian Ocean tsunami of 2004, safeguards to prevent a repeat of such a scenario have been put in place all over the world. These specialised early warning outposts allow scientists to forecast when a tsunami will hit the nearby coastline, down to within a couple of minutes. Scientists use a series of complex monitoring systems to track wave movements: devices are planted on ocean floors that can measure pressure increases, which are sent to buoys on the surface and then relayed to satellites transmitting data to monitoring stations on land.

In the deep ocean a tsunami has an amplitude of less than 1m. This makes the steepness of the wave so small as to be undetectable to the naked eye. However, tide gauge instruments can pick up these changes by measuring the height of the surface. They achieve this by means of an acoustic sensor connected to a vertical tube open at the lower end that's in the water. The acoustic sensor emits a sound pulse that travels from the top of the tube down to the surface before being reflected back up the tube. This way the distance to the water level can be calculated using the travel time of the pulse. The sensitivity of the system is maintained thanks to a number of filters which disregard small-scale effects like wind waves, allowing the gauge to measure sea-level changes down to 1mm accuracy.

least four that are thought to have occurred in a 300-million-year period.

Geologist Gary Byerly from Louisiana State University has identified traces of the first meteor-induced tsunami in South Africa and northwest Australia, by inspecting the oldest rocks on Earth. "When the asteroid hit, it was vapourised by the extreme energy of the impact," explains Byerly. "Condensation of this vapour produced droplets called 'spherules', which fell into the sea over the next few days and were deposited in layers on the seafloor."

Byerly estimates that the heat of the impact would have also evaporated the upper 30 to 300 feet of water in the oceans. "There was almost certainly bacterial life at this time. If the impact was made by a meteor 20 miles in diameter, it would have killed everything on the surface."

SHORE DEVASTATION

In deep ocean water a tsunami can travel unnoticed at speeds of up to 500mph, crossing an ocean in a day or less. A boat out at sea will barely register danger as the energy wave passes underneath it. Similarly, when a tsunami approaches the shoreline, there may be no sign of a Hollywood-style colossal wave at all. One reason for this is that resistance in the form of friction gradually slows down the movement of energy through the water. However, as the tsunami closes in, the progressively shallower water compresses its energy and forces water upward, causing waves as high as 30m to pile up and rush over the land. "The front end of the wave slows down as it reaches the coast while the back end powers up behind the front end," explains Professor Dale Dominey-Howes, co-director of the Australian Tsunami Research Centre. "That's why tsunamis flood land for many, many minutes and can travel many kilometres inland."

The distance between approaching waves can be between 100 and 300km, creating the illusion that the danger is over, when it has only just begun. This series of rushing waves and withdrawals is known as a 'wave train', resulting in huge loss of life, incalculable damage to property and lethal floating debris. Beaches can be stripped of sand that may have taken decades to accumulate, while trees and vegetation above the typical high-water level can be undermined. Indeed, mainland flooding caused by a tsunami can reach heights of more than a thousand feet. For this reason alone, the safest place to be is on high ground. "Anywhere with strong cliff lines where there is very deep water off the coastline," advises Dominey-Howes, "as tsunamis can't grow big where there's very deep water."

Tim Hardwick
Science writer
+ Tim is a freelance writer whose interests include science, technology and evolutionary biology. He also has a background in literary history.
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PLANT LIFE & PHYTOPLANKTON

Delve beneath the ocean waves and you'll discover a whole world of subaquatic plant life. Here are the forests of the big blue sea

WORDS BY **Dominic Reseigh-Lincoln**

The kingdom of oceanic plant life can be divided into two simple groups: seagrasses and algae/seaweeds. Some of these eukaryotic organisms are rooted to the seabeds, reaching up through the waters to feed on the sunlight, while others float, drifting through the ocean and producing colossal amounts of oxygen. One such wanderer is phytoplankton, which is one of the most abundant organisms on Earth.

These single-cell organisms – otherwise known as microalgae – are the foundation of almost every aquatic ecosystem. Divided into two groups – dinoflagellates, which use whip-like tails to propel themselves through the water, and diatoms, which rely on currents to power their travels – phytoplanktons are a major player in 'primary production' (photosynthesis). As a result, their creation of organic compounds for carbon dioxide helps power the delicate ecosystems in marine environments.

While phytoplanktons float near the surface, on the seabed there's another world of interesting things taking place. Red algae (rhodophyta) are some of the most diverse, and the largest, eukaryotes in the sea. With both single-cell and multicellular variants, red algae, which derives its colour from water-soluble proteins called phycobiliproteins, can also adhere to corals, thus forming striking and biodiverse reefs.

Elsewhere, green algae are by far the most common, ranging in size from microscopic organisms to much larger forms. This particular division of algae gets its blue/green-like colours from the green chloroplasts within. On reefs and on the seabed itself, brown algae also plays a key role. While its species isn't quite as diverse as other forms of algae (with around 1,500 known variants, including many types of seaweed), brown algae is vital to the conversion of nitrogen into forms that marine life can actually process.

Despite their home far beneath the waves, these sub-aquatic organisms still make an imperative contribution to the longevity of the world's oceans. Seagrasses found in lagoons and bays provide a source of food and habitation for small invertebrates and fish, which act as sustenance for larger fish. Underwater plants also help to stabilise sediment levels at a variety of depths and reoxygenate the waters.

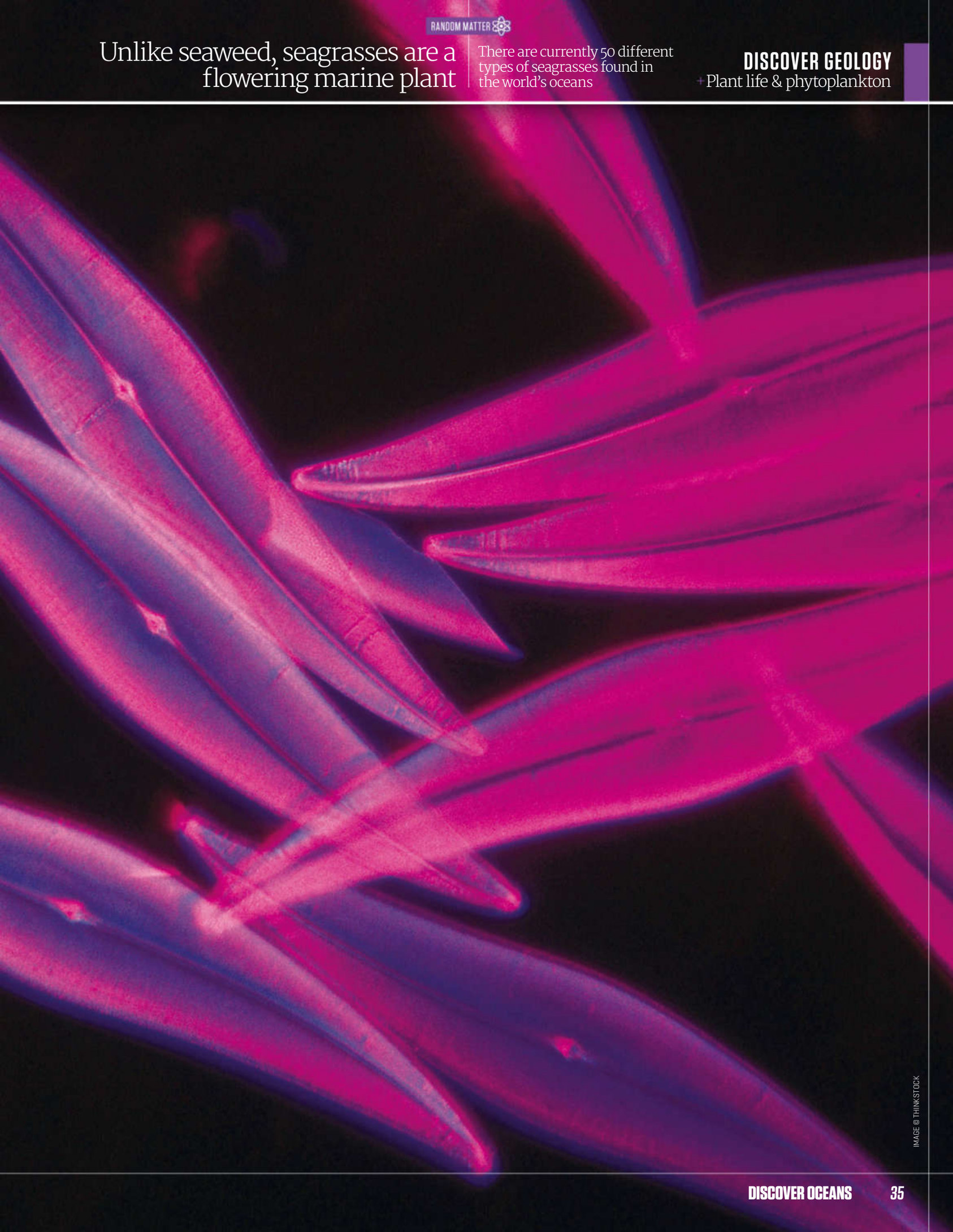
Sadly, for all its importance to the ocean's ecosystem, these marine plants are under constant threat. Oceanic pollution is choking much of our planet's plant life, creating dead zones that cause fragile ecosystems to collapse. Hopefully, the work of conservation groups such as Oceana and Greenpeace will turn the tide.

Dom Reseigh-Lincoln
Science writer
++ Dom studied veterinary medicine at university before deciding to pursue his love of journalism. *@furianreseigh*

PHYTOPLANKTON ARE THE FOUNDATION FOR ALMOST EVERY ECOSYSTEM ON EARTH

Unlike seaweed, seagrasses are a flowering marine plant

There are currently 50 different types of seagrasses found in the world's oceans



RANDOM MATTER

Seaweed goes well with ice cream

Jelly weed (Betaphycus speciosum) – a red seaweed – was collected by early American settlers and boiled to make jelly

5 amazing facts about seaweed

It's omnipresent on beaches, but how much do you know about the humble seaweed? Tougher than your average land plant, there's more to it than meets the eye...

WORDS BY **Tim Hardwick**

1. MEDICINAL SEAWEED

Due to their anti-inflammatory and anti-microbial properties, various kinds of seaweed have been used medicinally by humans over thousands of years. Ancient Romans prepared mixtures of herbs and seaweed to treat wounds, burns and rashes. There's even evidence that the Ancient Egyptians used algae to treat breast cancer. And modern research suggests they were onto something... Studies have found anti-tumour activity in kelp that could be used to fight leukaemia, while tests of kombo and wakame seaweed have indicated protective effects against genetic mutations linked to cancer. Perhaps the biggest gift seaweed gave to medicine, though, happened in 1812, when French chemist Bernard Courtois began extracting sodium and potassium from seaweed ashes for industrial use. One day Courtois made a mistake in the process, which led to clouds of violet vapour in his lab. He had discovered iodine – a primary ingredient of modern antiseptics and germ-killing products.

RIGHT Iodine found in seaweed is a key ingredient in contemporary antiseptics and cleaning products

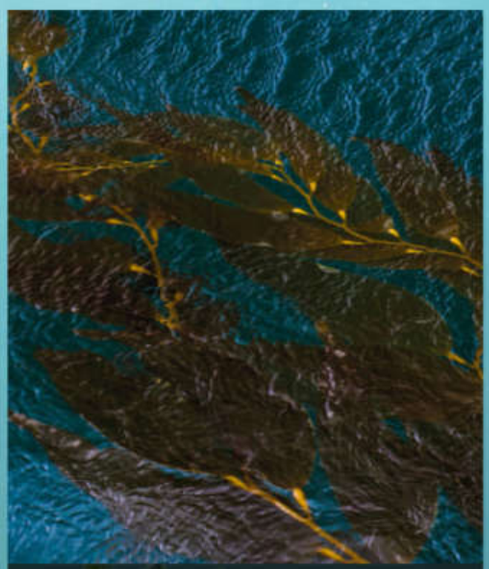
2. ALGA, NOT PLANT

Seaweed is not a plant but an alga. There are good reasons for this division in classification. For one, algae can be single-celled, whereas plants are always multi-cellular. Also, algae don't have vascular systems for the uptake and transport of water and nutrients like plants do, so each cell in a seaweed must obtain its own supply from its liquid environment. True, both plants and seaweed are photosynthetic and even have the same life cycle, but the similarities end there. Plants are generally rooted to the ground and cannot move, but many seaweed species drift with the currents. Not only that, plants feature complex reproductive systems and often rely on birds, insects and the wind for pollination. Seaweed, on the other hand, reproduces asexually or through the release of 'zoospores' that swim off and grow into new individuals.

Seaweed reproduces asexually. That's one reason why it's an alga not a plant

Seaweed comes in three colours

Seaweed exists in green, red and brown varieties, though blue-green algae is often considered a variety of seaweed as well



ABOVE Giant kelp is a beast of the ocean, its enormous fronds reaching up to 175 feet in length

3. LONGEST SEAWEED

Giant kelp, or to use its Latin name, Macrocystis pyrifera, is the longest species of seaweed in the world. Typically found on rocky seabeds in temperate waters around the Southern Hemisphere and northeastern Pacific, this Leviathan of the kelp forest can grow up to an amazing two feet a day, making it the fastest growing 'plant' (if it were a plant - see fact 2) in the world. Its fronds are held upright by gas-filled bladders at the base of its leafy blades and grow up towards the surface of the ocean, where a dense canopy forms. The giant kelp thrives in turbulent water where nutrient supplies are rich and abundant, allowing the seaweed to grow up to 175 feet in length. And even then it doesn't break or snap thanks to its tough but flexible stem-like 'stipes', which sway quite happily in strong ocean currents.

4. KELP FORESTS

It's not just coral reefs that ensure the biodiversity of the oceans. Giant kelp seaweed can form dense forests underwater and, like land forest ecosystems, they are critical to the survival of thousands of different species of marine animal. Thick branches not only anchor kelp to the seabed but also form a habitat for eels, snails and tiny lobsters. Sea urchins often thrive in this environment and can sometimes eat right through the anchoring holdfasts, resulting in kelp dieback. Luckily, sea otters find the urchins easy prey in the forest. Of course, there's always more seaweed to grow, its dense canopy of leaves that sits on the water surface providing safe shelter for further invertebrates like prawn, scud and sea stars. Mammals such as sea lions and seals also feed on the fish that gather in the kelp haven, and even grey whales have been known to graze in them.

Kelp forests provide a veritable feast for a huge array of aquatic life

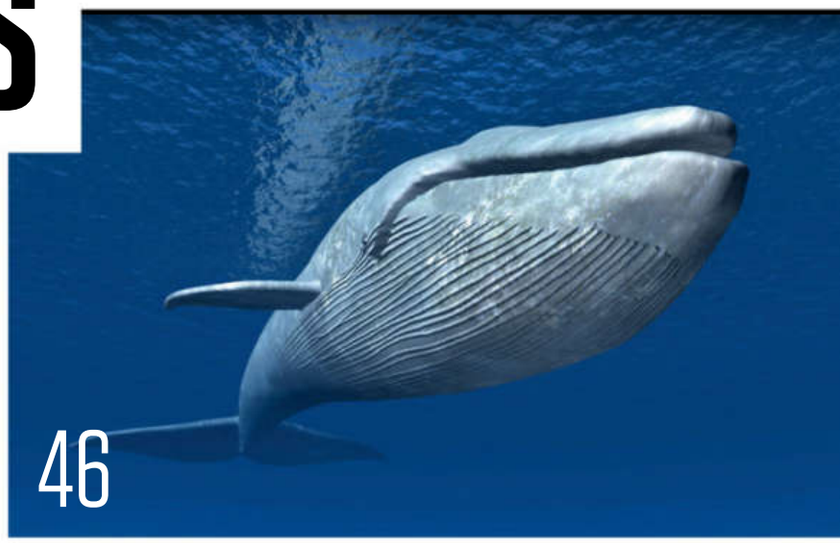
Goodbye fossil fuels, hello power supplied by seaweed. Could kelp supply the next generation of fuel?

5. THE NEXT BIOFUEL

Could seaweed farms replace fossil fuel-burning power stations? Some scientists think so. Sugar kelp, or Laminaria saccharina, is being studied by Norwegian scientists because it contains three times more potential biofuel energy than sugar beet. It also cleans up sea pollution emanating from fertiliser by absorbing excess nitrogen from the water. "Algae is capable of absorbing nitrogen from water as effectively as a wastewater treatment plant," explains Fredrik Gröndahl, a researcher at Sweden's KTH Royal Institute of Technology. Gröndahl is head of the Seafarm project whose goal is to develop a system for using seaweed as a renewable resource in Sweden. "We collect excess algae along the coasts and convert it into eco-friendly food, medicine, plastic and energy," he says. "We also cultivate algae out at sea and that creates all-year-round jobs."

Tim Hardwick
Science journalist
Tim Hardwick is a freelance writer whose interests include science, technology and evolutionary biology.

SEA ANIMALS



"BOX JELLYFISH HAS 500,000 HARPOON-SHAPED NEEDLES ON EACH TENTACLE"

PAGE 48

RANDOM MATTER

Squid ink has been used as writing ink

These days, humans tend to employ it purely in the kitchen

The venom of the lionfish, delivered by up to 18 dorsal fins, is purely defensive

MOUNTING A DEFENCE

To survive in the treacherous oceans, sea-bound life has developed many ways to fend off predators, from the subtle to the extraordinary

WORDS BY **MATTHEW BOLTON**

The ocean is swimming with predators and prey, like all animal ecosystems, and this naturally leads to evolution producing some quite intriguing and varied methods for vulnerable fish to evade their aggressors. While some are dramatic and violent, they can be quite simple, including camouflage and hiding. Some fish, such as the leafy sea dragon, resemble rocks or sea plants, with random skin patterns in the right colours, or leaf-like growths, enabling them to stay unnoticed when still. Some flatfish and octopi can change their colours completely to match their surroundings, mimicking its texture, enabling them to hide on any part of the sea floor. Flatfish will also bury themselves under the surface of the sea floor, staying as hidden as possible under the stones and debris.

While few fish match the genius versatility of that camouflage, many have aspects that make them hard to spot in the open water. In the soft light of the sea, a giveaway for a fish would be blocking the sunlight, appearing as a shadow, so many adaptations work to confuse that method of spotting them. Fish with reflective scales are very common, with the light bouncing

RANDOM MATTER

The longest flying fish flight measures 45 seconds

The incredible feat was recorded off the coast of Yakushima Island in Japan

FLOUNDERS: DISGUISE KINGS

How these incredible fish can match any surface they lie on...

+ The ability of flounders to hide themselves on the ocean floor is unparalleled. Not only are they able to bury themselves under a layer of sand, with just their eyes poking out, but they can actively change their colour to match their surroundings in stunningly sophisticated ways. In a matter of seconds, they can transform the appearance of their upper half to blend in with complex textures, including subtle colourations in sand. Incredibly, they can even mimic stark checkerboard patterns. They achieve this via cells in their skin called 'chromatophores', which contain pigments, and are controlled and released to adapt their colouring. Flatfish use their eyes to tell how they should change – having just one damaged eye can severely impair the effectiveness of their adaptive camouflage.

IMAGES © THINKSTOCK

ABOVE Now you see it... Flatfish match chameleons in the camouflage stakes

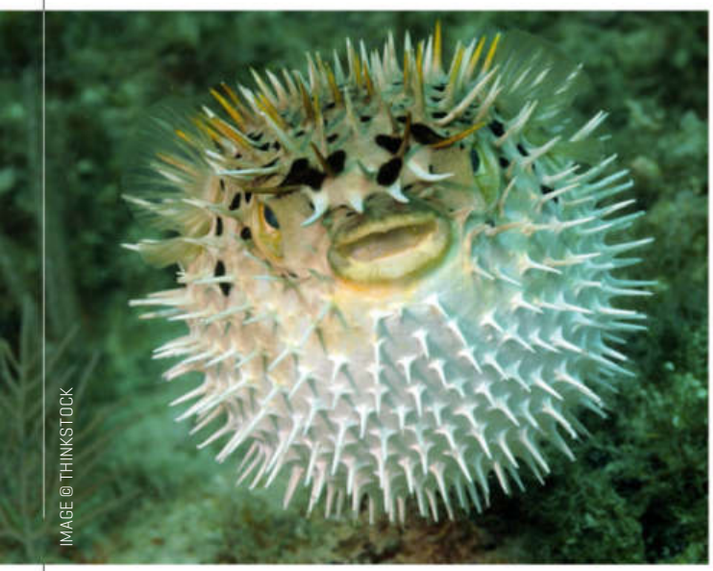


IMAGE © THINKSTOCK

BELOW The factually named blowfish expands its body to fend off predators

THE PUFFERFISH IS CAPABLE OF INFLATING ITS STOMACH AND IT'S ALSO INCREDIBLY POISONOUS

off them in ways that make them extremely difficult to pick out in the shifting, refracting waters.

CONCEALED BY TRANSPARENCY

Many fish, including jellyfish, are at least partly transparent, hiding by allowing the light through, so they're hard to see. Lots of fish have different colouring on their top side compared to the bottom. Usually the top will be darker and the bottom lighter, so that if looked down on from above, their top matches the inky darkness of the ocean depths, while if viewed from below, their shade matches the light shining through the water. Even fish that live quite deep make use of this tactic, except instead of simply being a lighter shade underneath, they have bioluminescent organs that can mimic the light of the surface above, disguising their shadowy shape.

Some fish use less passive means to defend themselves. One of the more shocking is... well, electric shocks. The most famous electric fish is the electric eel, which can deliver a dangerous 600-volt discharge, but it lives in freshwater only – it's found in South American rivers, including the Amazon. The sea contains its share of fish capable of bioelectrogenesis, though. There are many species of ray with large electric organs, and they are capable of producing around 200 volts of discharge, which can stun larger fish. Certain species of the stargazer fish can emit an electric discharge, too, as can some catfish.

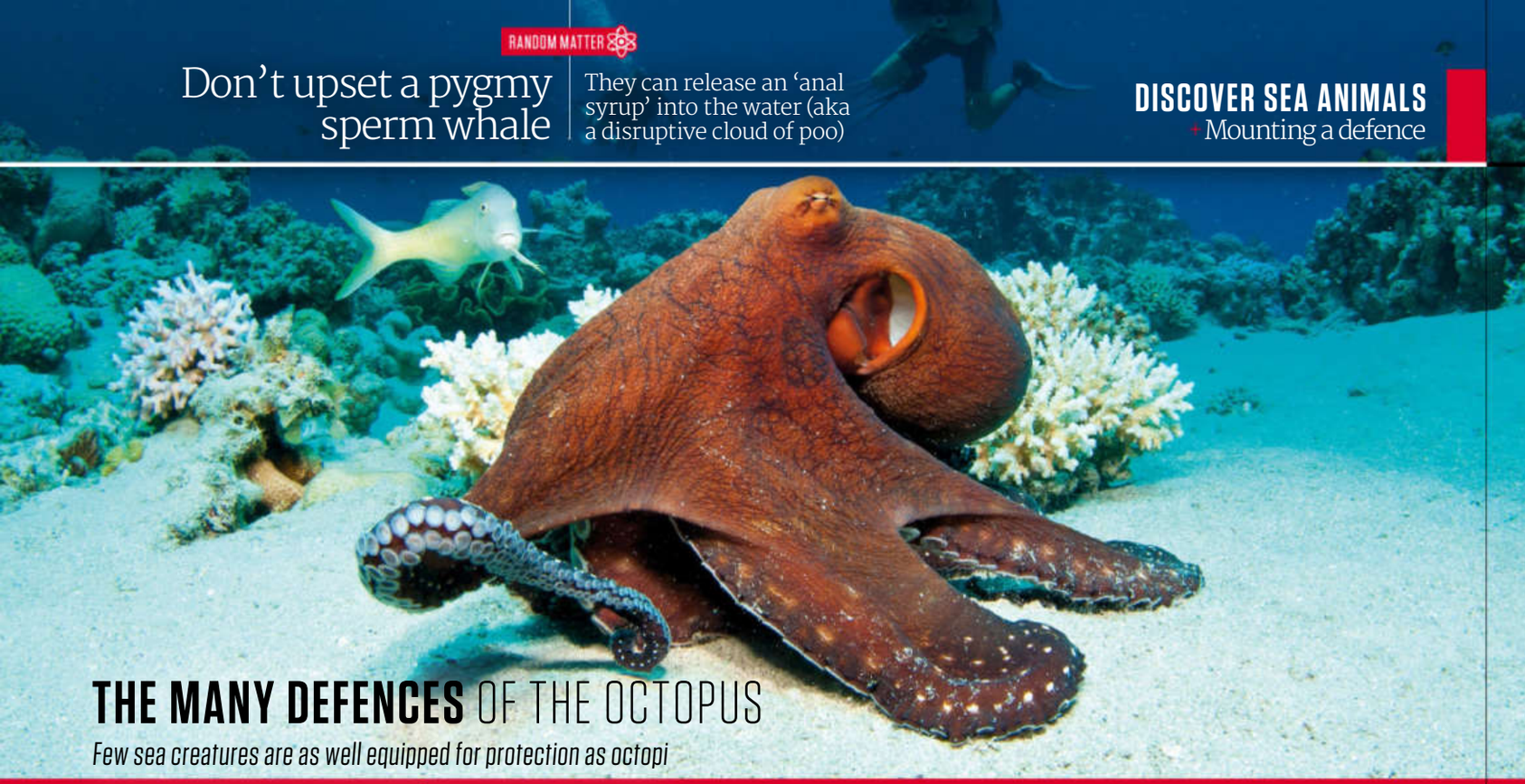
STING IN THE... TENTACLE

Another animal likely to give any predator a painful experience is the jellyfish. Jellyfish tentacles are bristling with nematocysts – microscopic barbed structures that are ejected when the surface of the tentacle comes under pressure, injecting venom into the unsuspecting attacker. Different species of jellyfish have different levels of sting, as is common with venoms – some barely affect humans, while others are capable of killing. Jellyfish are classified alongside sea anemones (despite the plant-like appearance of anemones, they're animals) and it's this same nematocyst mechanism that makes anemones dangerous.

One of the most famous and spectacular defences of any sea creature is the ability of cephalopods – including squids, octopi and cuttlefish – to produce clouds of ink. It's a very clever and efficient escape mechanism, heightened by the cephalopod's capacity to propel

Don't upset a pygmy sperm whale

They can release an 'anal syrup' into the water (aka a disruptive cloud of poo)



THE MANY DEFENCES OF THE OCTOPUS

Few sea creatures are as well equipped for protection as octopi

INK

Like squids and cuttlefish, octopi can release a cloud of ink to disguise their escape or simply to act as a distraction. The ink is thought to impair the ability of creatures such as sharks to smell their prey, as well as blocking the octopus from view.

CAMOUFLAGE

Like flounders, octopi are equipped with colour-changing cells that enable them to hide against the seabed. Some species even use muscles in their skin to change their texture, appearing more like a craggy rock. They also use colour changes as a warning: the blue-ringed octopus becomes a hazard-indicating yellow when threatened.

ARM AUTONOMY

In a similar way to how some lizards can detach their tails to evade predators, octopi can detach an arm, which continues to move and act on its own, reacting to the environment around it as if still part of the octopus, confusing a predator who thinks it has caught the full thing.

MIMICRY

The mimic octopus is known to hide in the seabed, sticking a single tentacle out and colouring it like a venomous sea snake. It also changes its colour and fans its arms to look like the spiny, venomous lionfish – a much less appetising dinner choice.

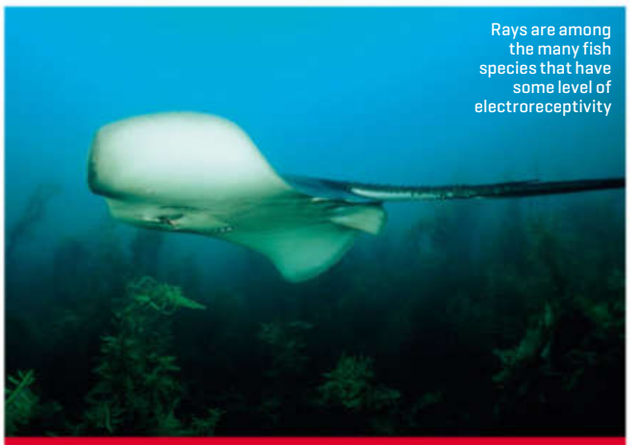
themselves by ejecting jets of water. The ink storage sacs connect directly to the siphon, which the squid or octopus uses for propulsion. When the ink is released, it's fired out along with a jet of water, which not only helps to spread the ink more effectively, increasing confusion, but also sends the squid or octopus away from the point of danger at the same time, giving it a head start with its escape.

INK-JET ESCAPE

And those aren't the only two ways that ink is used for defence. Smaller clouds of ink featuring high mucus levels can also be released, which remain in smaller, darker shapes, rather than diffusing. A cephalopod might release several of these, and predators have been observed to attack them instead, allowing the squid or octopus to escape through the distraction of a decoy, rather than in the confusion of the cloud.

When escape isn't an option, some fish defend themselves simply by creating so much trouble that the predator thinks twice about eating them. Pufferfish are famously capable of inflating, filling their stretchable stomachs with air, but they are also equally toxic. Even if a predator isn't put off by their increase in size, or the spines that erect when a pufferfish inflates itself, some of the pufferfish's organs contain a highly dangerous neurotoxin. Very large predators might be able to survive this dose of poison, but it's still powerful enough to kill humans.

Similarly, stingrays are equipped with large, extremely sharp barbs on their tail that can inject a powerful venom. There are many other fish that use venomous barbs or spines to stave off an attack, including the most venomous fish in the world, the reef stonefish. Its dorsal fin is lined with spines that are capable of piercing



Rays are among the many fish species that have some level of electroreceptivity

THE AQUATIC NATIONAL GRID

+ Fish such as rays can generate a large enough electric shock to warn potential predators of the dangers of eating them, but they also have an extremely complex series of electroreceptors – organs that can sense electric fields – enabling them to detect other creatures even in the darkest depths, or when vision is otherwise impaired. Some fish can even modulate their own electric field as a way to communicate.

RANDOM MATTER

Reef stonefish can survive 24 hours out of water

And their venomous spines are still active, so watch your feet!

NO CLOWN TEARS

With no defences of their own, clownfish use anemones as their guardians

+ Anemones are predatory animals that look like plants, but attack and defend themselves with venom. What fish would want to go near that? Well, clownfish would, but that's about it – and that's the way it likes it. Clownfish can survive happily within the stinging arms of anemones, so they nest and live among them, and form a symbiotic relationship with their host.

Hiding in an anemone's many dangerous arms gives the clownfish protection from predators, and ensures that its nesting sites stay untouched. In return, the clownfish also helps to chase off the anemone's predators. It's thought that the clownfish's colourful markings may lure fish in, where the anemone can sting them for devouring. The clownfish might get scraps of this food, and can also feed on dead arms from the anemone. It also appears that the clownfish and anemone simply being active in the same space has benefits, such as increasing aeration, allowing the anemone to grow faster. Clownfish waste also provides nutrients for the anemone.

What is it about the clownfish that makes it suited for living in anemones where other fish aren't (there are some other species that live in anemones, but they're rare)? It's thought that a coating of mucus on the clownfish's skin provides protection against stings. In some cases, clownfish appear to have full innate protection against the stings, while in other cases they acquire it by repeatedly rubbing against the anemone, until their coat adapts and protects them. It's thought that this behaviour may also help to confuse the anemone into being unable to distinguish the clownfish from itself over time.

Though clownfish and anemones don't require one another to survive, they make an excellent pairing, and the cute, defenceless clownfish gets to live a much longer life with a dangerous, venomous bodyguard fending off its predators.

LEFT Catfish is another sea animal that uses electricity as a form of defence

BELOW Flying fish have been recorded remaining airborne for 45 seconds

IMAGES © THINKSTOCK

the soles of boots, and the venom is quite capable of paralysing and killing whatever's on the receiving end, including humans.

SAFETY IN NUMBERS

It's advantageous for small fish to act with such potency, but not all can. Instead, many seek truth in the phrase 'safety in numbers' and swim together in schools in order to avoid predators.

There are two potential benefits to fish swimming in large groups. The first is simply that each individual fish is less likely to be eaten when there are many other options around, compared to if it were spotted swimming on its own by a predator. The second is more sophisticated – by swimming close together and moving fluidly as one, the fish can present themselves as a single body, looking like a much larger fish, more capable of fighting to defend itself, to their predators.

Despite all of these incredible defence methods, some fish avoid being eaten in the simplest way possible: athleticism. Reef-based fish are often capable of sharp bursts of speed and are highly manoeuvrable, enabling them to dart their way through the reef's complex structures, with their thin bodies allowing them to escape through small gaps. Thin-profiled species, such as angelfish, can also quickly dart into narrow spaces in rocks to hide.

Finally, some fish don't even escape in the water, but take to the skies when predators are near. Flying fish can burst out of the water into the air, up to three metres in height, then use specially adapted elements of their bodies, such as enlarged pelvic fins, to glide in the air for up to 100m before returning to the sea, leaving a confused hunter in their wake. DS

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THE HAGFISH: SLIMING ITS WAY OUT OF DANGER

THE ONLY LIVING ANIMAL WITH A SKULL BUT NO VERTEBRAL COLUMN IS MORE FAMOUS FOR GUNK

+ The hagfish, also known as the slime eel, has a unique and especially intriguing – if rather disgusting – defence mechanism. When under attack, it can produce a mucus from its body that, upon mixing with water, rapidly grows into a very large (up to 20 litres) mass of gelatinous slime. This has the immediate effect of making the long, thin fish hard to grasp for a predator, but it's also thought that this gel actually acts as an impairment to gill function, effectively clogging up the predator's ability to breathe. The hagfish can clean the slime off itself by wrapping around its own body and moving along its length to wipe the gel away (an action that may also help it to break free from the grip of a predator), which would ensure the gel doesn't interfere with its own gills. It may not be dignified, but the hagfish's defence is certainly effective – most of its predators are birds or mammals, rather than other marine creatures.

IMAGES © WWW.FLICKR.COM/PHOTOS/DIRTSAILOR2003

The hagfish is eel-shaped, but emits a crateful of slime when faced with predators

FLYING FISH CAN REACH THREE METRES IN HEIGHT AND GLIDE IN THE AIR FOR UP TO 100 METRES

SCIENCESHOT

+Stunning images from the Earth's oceans

THE BLUE WHALE

An animal so big it even dwarfed the Leviathan-like dinosaurs of the ancient Earth

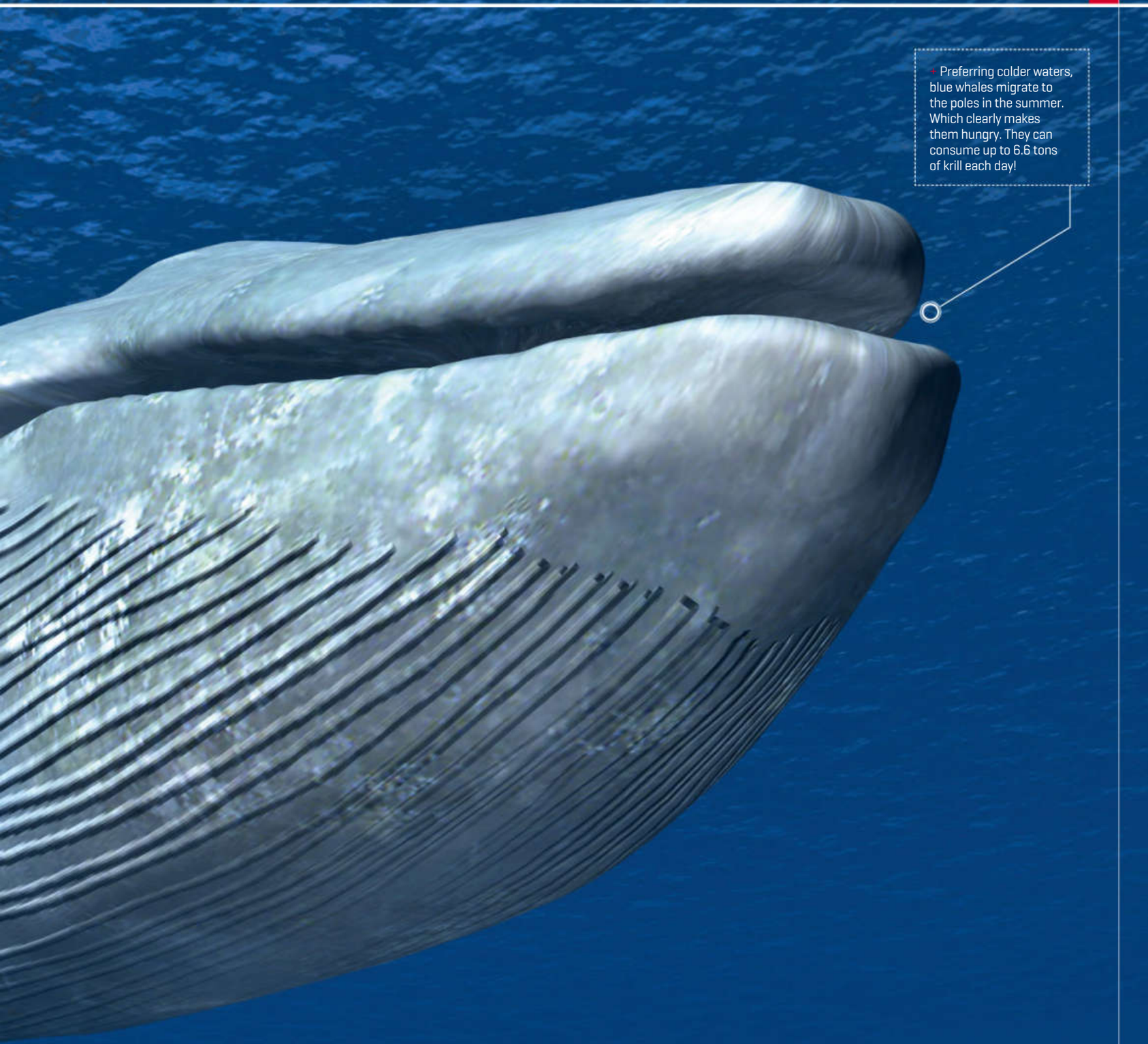
PHOTO © THINKSTOCK

With the largest specimens recorded reaching a staggering 30 metres in length and 200 tons in weight, the blue whale (Balaenoptera musculus) is one of the last true giants of the animal kingdom. Up until the beginning of the 20th century, this gargantuan marine mammal had abundant populations in almost every ocean in the world – most notably in Antarctica. At the time, it's estimated global blue whale populations were between 200,000 and 300,000, but six decades of intense, unregulated whaling brought the blue whale to near extinction. Thanks to new conservation laws, the current figure of 12,000 is slowly rising, ensuring this gentle giant isn't condemned to the history books.

+ Blue whales are also characterised as 'rorquals', which denotes the longitudinal pleats that run through its throat. These regularly expand, enabling it to consume huge amounts of water.

The blue whale has three known subspecies

The pygmy blue whale (24m long), the Northern Hemisphere variant (27m) and the Antarctic blue whale (29m)



+ Preferring colder waters, blue whales migrate to the poles in the summer. Which clearly makes them hungry. They can consume up to 6.6 tons of krill each day!

THANKS TO NEW CONSERVATION LAWS, THE CURRENT FIGURE OF 12,000 BLUE WHALES IS ON THE RISE

RANDOM MATTER

Jellyfish are made up of around 95% water

That said, ancient jellyfish predecessors actually possessed a skeletal structure

The life and times of a jellyfish

With no brains, no heart and no blood, it's amazing that jellyfish have existed for 650 million years!

WORDS BY **Christian Hall**

Jellyfish are some of the most alien-looking creatures of the sea and are found in every ocean of the world. There are more than 3,500 known jellyfish, in all shapes and sizes, and they are just one part of a 10,000-strong mainly marine animal species called Cnidaria – a species that sits in the 'phylum' group in biology.

Cnidaria are categorised by the central feature of cnidocytes – specialised cells that they use mainly for capturing prey. Their bodies consist of a non-living jelly-like substance, and they come in two main forms: the dome-shaped medusae that swim, and the stationary polyp that is anchored to a spot on the sea floor. Their lives are very different at these two stages, in looks as well as behaviour, but both forms have a single orifice and body cavity that are used for digestion and respiration.

"What makes the entire phylum Cnidaria (coral, anemones, jellies) unique is that this is the oldest true animal species in the animal kingdom after sponges and ctenophores," says Angel Yanagihara, director of the Pacific Cnidaria Research Lab. "The Cnidaria all also have cnidae (tiny capsules which contain a coiled tubule) and potent venoms."

The name, of course, is a misnomer – they're not fish at all, as real fish are vertebrates. That's why many prefer the terms jellies or sea jellies. Sea jellies include Scyphozoa, from the Greek word 'skyphos', referring to a drinking cup that describes the bell shape of jellyfish. It's that part of the jellyfish that we all recognise so well, and the world's oceans are filled with an incredible variation in colour, size and characteristics. Take a look to your right for some of the more bizarre jellyfish species.

THE OCEAN'S HEARTBEAT

The way the medusae form of jellyfish moves through the oceans is also

IMAGE © THINKSTOCK

THE OCEAN'S WEIRDEST JELLIES

Weird, beautiful, unique – whatever you call them, these sea jellies stand out

FLOWER HAT JELLYFISH

+ Looking almost like a brain inside a space helmet, with a flower garland, this jellyfish lives off the Japanese coast and grows to just 15cm diameter. Its diet consists mostly of small fish, which are caught with the tentacles.

STALKED JELLYFISH

+ The stalked jellyfish uses a sucker at the bottom to attach itself to a marine plant, such as eelgrass, seaweed, rocks or the seabed. They usually have eight arms, on which are numerous tentacles that are used to catch their prey.

ATOLLA JELLYFISH

+ This species of deep-sea crown jellyfish lives in oceans around the world and is bioluminescent. When attacked, it'll launch a series of flashes, whose function is to attract other predators who will be more interested in the attacker than itself.

FRIED EGG JELLYFISH

+ Common in Mediterranean waters, Cotylorhiza tuberculata grows to around 35cm across and is shaped like a fried egg. A similar jellyfish, Phacellophora camtschatica, grows to 60cm across and is also known as the fried egg jellyfish or egg-yolk jellyfish.

DARTH VADER JELLYFISH

+ The deep ocean is the last place you would expect to see the imposing sight of Darth Vader's helmet, but in 2010 that's what happened! Bathykorus bouilloni, as it's otherwise known, is an arctic sea dweller and is tiny at just 2cm across.

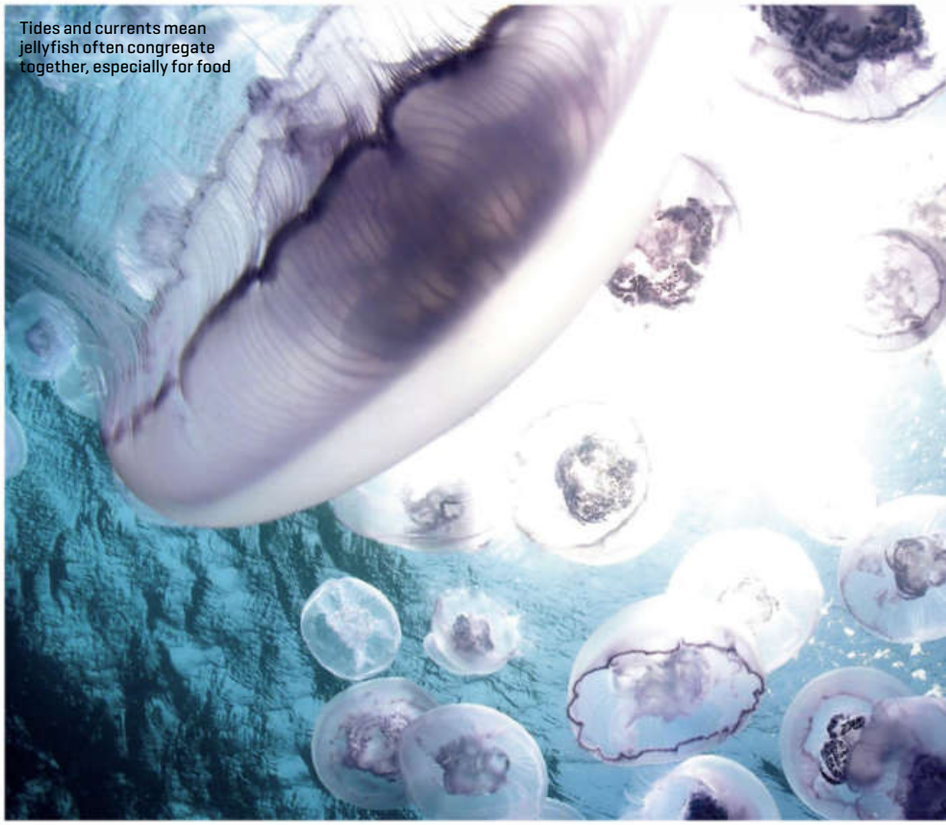
RANDOM MATTER

Box jellyfish venom is the world's deadliest

Each tentacle has about 500,000 harpoon-shaped needles that injects venom into the victim

Despite their thrust, jellyfish move slowly

Jellyfish don't have brains, but they do have nerves



Tides and currents mean jellyfish often congregate together, especially for food

a distinctive trait of the species. A jellyfish propels itself along by opening and closing its bell. The animals have a ring of muscles around the edges of their bell, which contracts the bell. This contraction forces out water that was stored inside the bell and off they go.

Based on mathematical calculations, scientists believe jellyfish are the world's most energy-efficient creatures. A 2013 research project in Massachusetts found that jellyfish actually swim using a dual-propulsion system that involves two vortices. As the first vortex (the 'starting vortex') pinches off, a second vortex forms, spinning in the opposite direction (the 'stopping vortex'). When a jellyfish relaxes its muscles and opens its bell, the stopping vortex moves up underneath the jellyfish, giving it a secondary push. This second thrust accounts for around 30% of the distance travelled by the jellyfish for each movement cycle.

SCIENTISTS CALCULATE THAT JELLYFISH ARE THE WORLD'S MOST ENERGY-EFFICIENT CREATURE

Despite such a thrust, jellyfish move slowly and where they end up is largely determined by tides and currents, so they can become concentrated. "While they have no central brain, they do have nerves and can recognise when they are in a good food concentration and can follow a gradient of food concentration by slowly swimming along it," says David Conway, associate fellow at the Marine Biological Association (UK).

The use of nerves to recognise stimuli isn't the whole story, however. "The vertebrate definition of 'brain' is a bit simpleminded," says Yanagihara. "The cubozoans have visual apparati that reconstitute the evolutionary history of light perception on this planet. The presence of visual capacity and distinct visual driven behaviours is evidence that the four eye stalks may act as individual visual processing centres – perhaps four brains!"

Jellyfish also have a knack of adapting to their food trail quickly, as they can grow or shrink depending on food supply. When there isn't much food, a jellyfish can shrink in size so it needs to eat less. It grows back up to its full size when there is lots of food.

A LIFE LESS ORDINARY

So how do jellyfish grow up? Well, how jellyfish reach their adult state is one of the ocean's most fascinating stories. The classic life cycle is that a male broadcasts sperm, which is picked up and internally fertilised by a female. Embryos are shed and develop into 'planula larva' that settle on the sea floor and become a polyp.

The polyp then metamorphoses (asexually) into a jellyfish or buds off into a juvenile medusa. But every part of that classic life cycle varies across the group, including species with no jellyfish stage, species with no planula and species with no polyp stage. "Different species are known to 'de-differentiate' from the jellyfish stage and reconstitute as a polyp, rendering them theoretically immortal like Turritopsis – the so-called immortal jellyfish," says Allen Collins, zoologist at NOAA's National Systematics Lab.

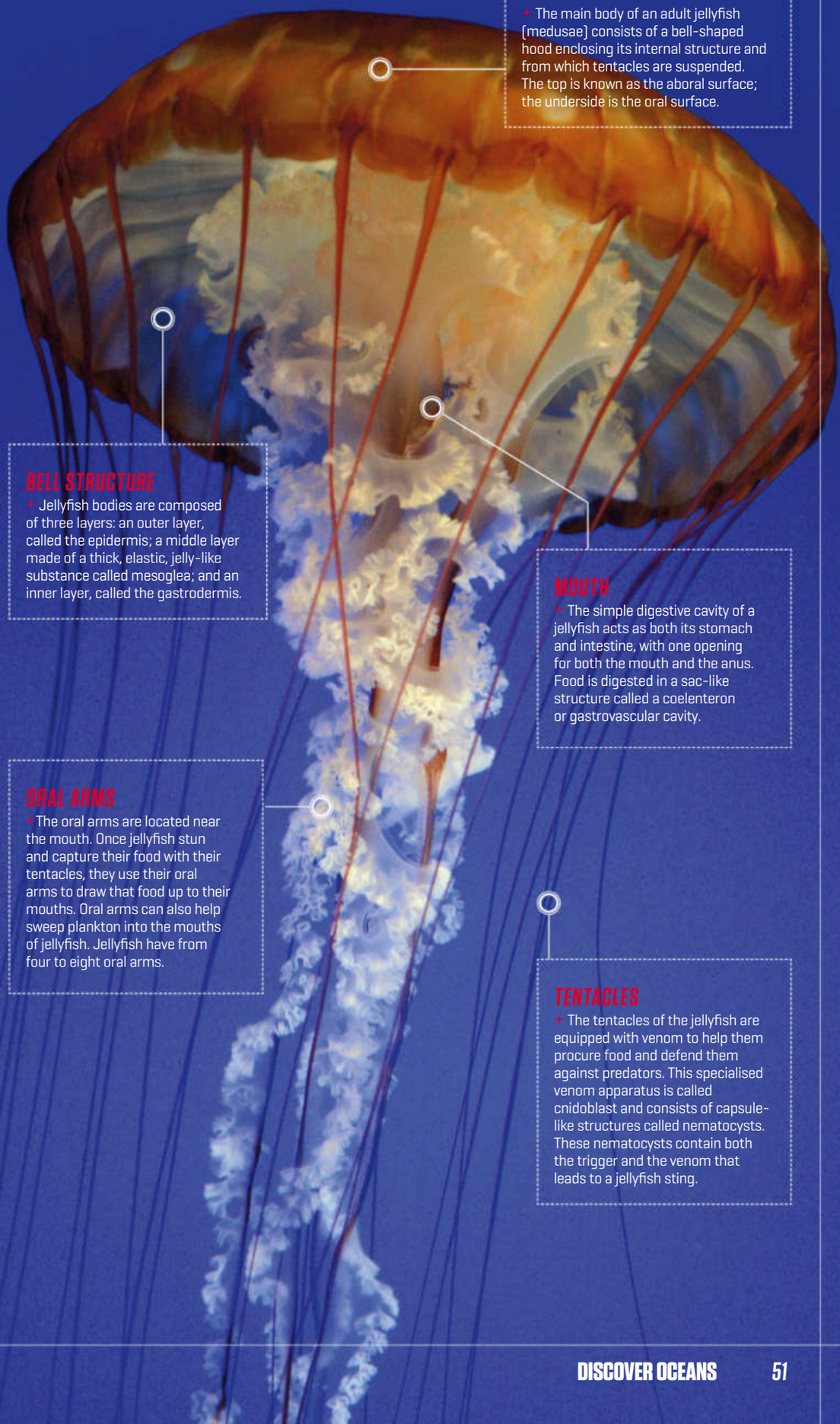
The immortal jellyfish is one of the most fascinating species of all. They have a polyp stage that also produces male and female pelagic

medusae. "The difference is that, in times of stress, the medusa can change back into a polyp, missing out the planula stage, so in theory revert to their juvenile form to start the process again, so could be considered immortal," says Conway. However, many will die of disease or will be eaten by predators.

Predators are part of the natural order, but how are they being affected by us? "There's no question that some jellyfish populations are increasing in some coastal areas of the world," says Lucas Brotz of the Institute for the Oceans and Fisheries, University of British Columbia. "There are also links between increasing jellyfish populations and human activities, including global warming, overfishing and pollution." These links are difficult to prove experimentally, but the evidence for all of them is mounting.

Christian Hall
Science writer
+Christian is the editor of *MacFormat*, but also has a passion for science and the seas. @*christian_hall*

THE ANATOMY OF A JELLYFISH



THE BELL
+ The main body of an adult jellyfish (medusae) consists of a bell-shaped hood enclosing its internal structure and from which tentacles are suspended. The top is known as the aboral surface; the underside is the oral surface.

BELL STRUCTURE
+ Jellyfish bodies are composed of three layers: an outer layer, called the epidermis; a middle layer made of a thick, elastic, jelly-like substance called mesoglea; and an inner layer, called the gastrodermis.

MOUTH
+ The simple digestive cavity of a jellyfish acts as both its stomach and intestine, with one opening for both the mouth and the anus. Food is digested in a sac-like structure called a coelenteron or gastrovascular cavity.

ORAL ARMS
+ The oral arms are located near the mouth. Once jellyfish stun and capture their food with their tentacles, they use their oral arms to draw that food up to their mouths. Oral arms can also help sweep plankton into the mouths of jellyfish. Jellyfish have from four to eight oral arms.

TENTACLES
+ The tentacles of the jellyfish are equipped with venom to help them procure food and defend them against predators. This specialised venom apparatus is called cnidoblast and consists of capsule-like structures called nematocysts. These nematocysts contain both the trigger and the venom that leads to a jellyfish sting.

CREATURES OF THE DEEP

Living at depths greater than 1,000m requires myriad of unique and jaw-dropping adaptations...

WORDS BY **James Witts**

It's an oft-used quote that man knows more about space than the ocean. Now, no disrespect to Stephen Hawking and his brethren but as we don't know the exact size of space, that can't be proved. But the sentiment's based on the fact we've sent 12 people to the moon since 1969 compared to just three men descending to the deepest part of the ocean, the Mariana Trench. According to NOAA (National Oceanic and Atmospheric Administration in the US), the ocean covers 71% of the Earth's surface and contains 97% of the planet's water, yet more than 95% of the underwater world remains unexplored.

Less mysterious is life in what's termed the intertidal zone, where water meets the land, and the epipelagic zone, which broadly covers the upper sunlit zone of the ocean. Here, plant and animal life flourishes thanks to photosynthesis. But plunge deeper than around 100–200m and light fades; beneath 1,000m we're talking a dark abyss. And that dark abyss comprises around 79% of the Earth's entire biosphere, which is the global sum of all ecosystems.

It's here, where darkness reigns, that some of the world's most unusual-looking creatures inhabit. Take the vampire squid – a small squid with a gelatinous body whose eight arms are linked by a think webbing of skin and features eyes that are proportionally the largest of any known creature. Or the blobfish, found at depths of 1,200m and beyond in the

The giant spider crab lives up to 1,000ft below the surface

RANDOM MATTER

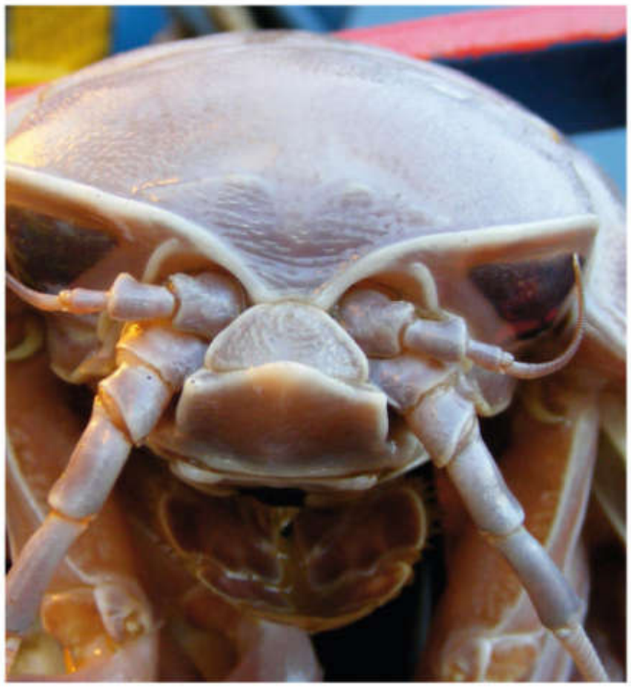
It can measure up to 12ft from claw tip to claw tip… and could nip your toe off!

THE GIANT TUBE WORM

A flourish of deep red in the deep-sea abyss…

+ Giant tube worms remained the preserve of the deep-sea only until man discovered hydrothermal vents in the late 1970s. This chemically-rich but toxic mix and huge temperatures pouring out of the vents would prove fatal for most species; giant tube worms thrive here. That's down to bacteria that live inside them and convert chemicals from the vents into organic molecules that provide food for the worm. Giant tube worms grow up to eight feet long and possess no mouth or digestive tract. Hence, the relationship with the bacteria. That bright red colour stems from huge amounts of haemoglobin and blood, which transfers nutrients.

Giant tube worms glow red thanks to huge levels of haemoglobin



PRESSURE 2,500M DOWN IS THE EQUIVALENT OF AN ELEPHANT STANDING ON YOUR TOE

deep waters off Australia and New Zealand and whom resembles a, well, big blob of skin.

Seen through human eyes they might not win any beauty competitions, but each tentacle, each bulbous midriff, derives from adapting to the physical characteristics of the deep sea. But before we delve into how deep-sea animals cope with the demands of their environment, like pressure, temperature and food, it's relevant to see how the oceans and their subsequent lifeform are geologically separated…

PELAGIC AND BENTHIC

The oceans are divided into two realms: the pelagic and benthic. Pelagic refers to the open water in which swimming and floating organisms reside, which are called the pelagos. The pelagic is divided further based on depth into: epipelagic, less than 200m where photosynthesis can occur; mesopelagic, between 200m–1,000m where sunlight is faint but not strong enough for photosynthesis to occur; bathypelagic, 1,000m–4,000m; abyssopelagic, 4,000m–6,000m; and hadopelagic, 6,000m to around 11,000m, like the deepest oceanic trenches. No sunlight penetrates the last three zones.

Benthic zones refer to the bottom sediments and land surface of a body of water. Life here enjoys a very close relationship with the bottom of the sea, with organisms either swimming just above it, permanently attached or burrowed inside. Similar to the pelagic zones, these are broken down as: subtidal, to about 200m; bathyal, to around 4,000m; abyssal, 4,000m–6,000m; and hadal, 6,000m–11,000m.

Why is this important? Because understanding about how life adapts to the characteristics of each zone ultimately teaches us more about the Earth and life itself. And part of that understanding stems from seeing how each organism copes with numerous environmental challenges…

COPE WITH PRESSURE

If you are at sea level, you have one atmosphere's worth of pressure

Pacific viperfish have been found 4,500ft down

Their teeth are so huge that they can't close their mouths

ILLUMINATING THE OCEANS

Bioluminescence – production of light by living organisms – is common below 1,000m. The reasons are many...

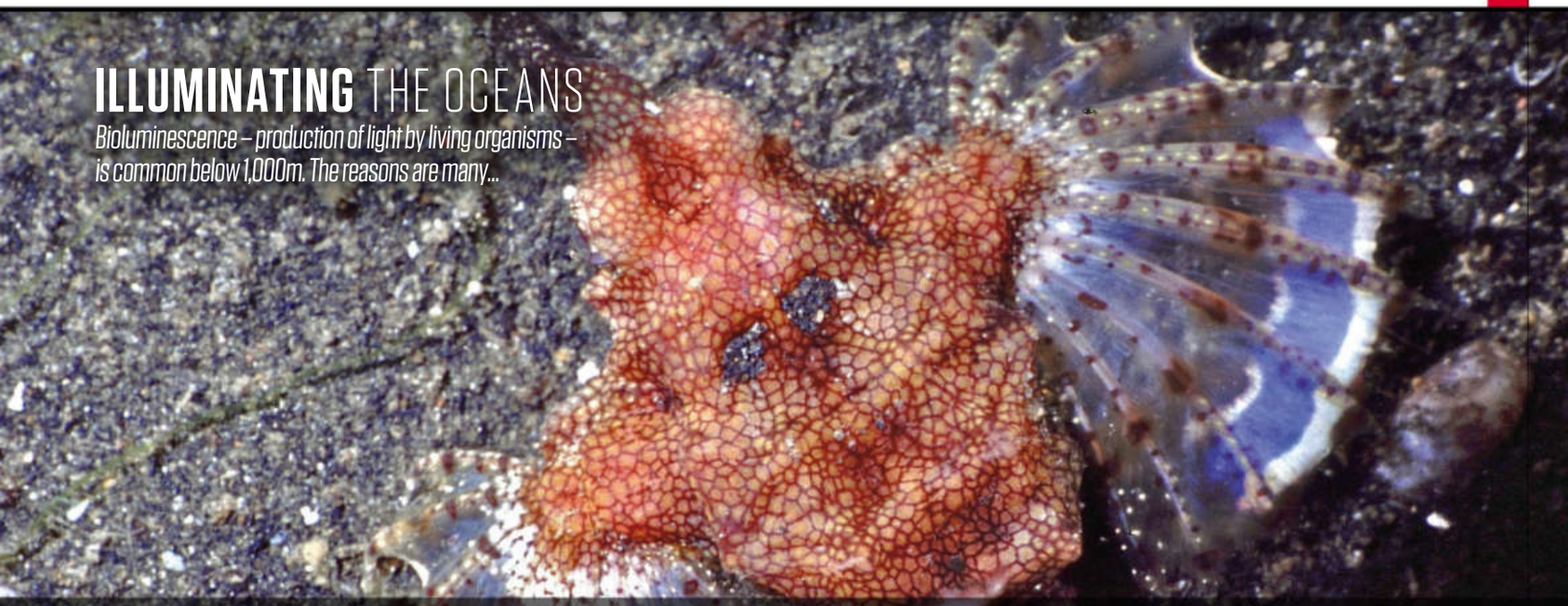


IMAGE © BERNARD DUPONT

HEADLIGHTS

Some fish have evolved forward-facing light organs called photophores to act as aquatic torches. The lantern fish is one such example who emits a weak blue, green or yellow light. Luminous patches at the base of the fin complete the neon look.

ATTRACTING MATES

Light patterns are arranged in gender-specific patterns to attract the opposite sex. This is a common tool employed by worms and tiny crustaceans, and is a useful one when you consider the low odds of finding a deep-sea partner to reproduce with.

ATTRACTING PREY

Animals, like the dragonfish pictured, use light to lure prey toward their mouths. For instance, small plankton are drawn to the bioluminescence around the beak of the Stauroteuthis octopus. More famously, the deep-sea anglerfish lures prey with a bioluminescent barbell.

VANISHING ACT

Bioluminescence is also used as a camouflage in a process known as 'counterillumination'. Photophores in the bellies of some mesopelagic fish emit blue light that matches the faint sunlight from above, making the fish invisible to predators below.

ATTACK AND DEFENCE

Some animals use bioluminescence to stun their prey. For example, some squid send out bright flashes that stop a prey in its tracks. Conversely, some marine life uses it as a defence mechanism, lighting up to illuminate the attacker in the hope of attracting an even bigger predator.

pushing down on you. In other words, the pressure inside your lungs is the same as the pressure of the air around you, which equates to 1.033kg per cm^2. This is one atmosphere of pressure. In the ocean, for every 10m you sink, the pressure increases by one atmosphere. So at 2,500m, for example, you'd have 250 atmospheres of pressure pressing down on you. That's the equivalent of an elephant standing on your big toe. It begs the question: how do creatures cope with these extreme pressures?

Some organisms use what's known as 'piezolytes'. These are small molecules that, for reasons that aren't yet understood, prevent pressure from distorting large molecules.

One of these piezolytes is trimethylamine oxide (TMAO). This molecule enjoys the dubious honour of causing that fishy smell. TMAO is found at low depths in marine life like shrimps, but increases in other fish thanks to greater depth and pressure. One example is the grenadier that inhabits depths of 200m–6,000m, and really lets out a pong!

In general, to cope with increasing pressure, many fish don't exceed 25cm in length, while researchers have discovered that the deeper the creatures live, the more gelatinous their flesh (blobfish!) and more minimal their skeletal structure. All cavities that would cave in under pressure are also eliminated like swim bladders.

CHILLED ENVIRONS

As well as overcoming pressure, organisms face temperature differences the deeper they reside. Take the tropics, for instance. It's rare that you'll find swimming waters that don't tip over 20°C. Enter deep seas and it's a different story. Excluding hydrothermal vents, where emerging water can reach nearly 500°C, temperature remains a constant -1°C

JAMES CAMERON'S DEEP-SEA EXPLOITS

+ On 26 March 2012, Canadian James Cameron, director of such Hollywood behemoths as Titanic and Terminator, reached the Challenger Deep, the deepest part of the Mariana Trench, a crescent-shaped trench in the Western Pacific, just east of the Mariana Islands near Guam. Squeezed into his Deepsea Challenger vehicle, Cameron plunged nearly seven miles to become the first human being to reach the near-seven-mile depth solo.

IMAGE © JAMES CAMERON

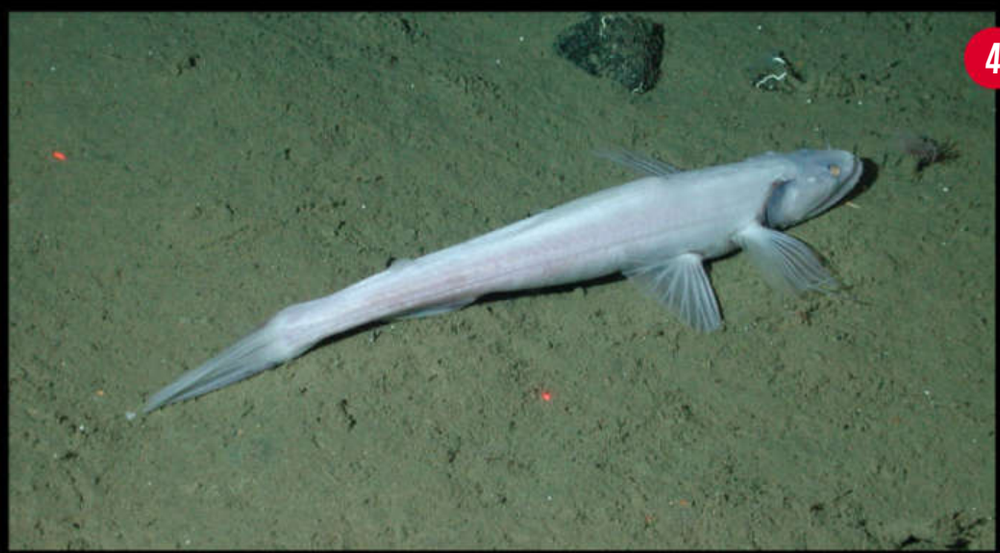
RANDOM MATTER

Gulper eels live around 3,000m beneath the surface

Their huge jaws allow them to consume prey as large as they are

LIFESTYLES OF FIVE DEEP-SEA CREATURES

Animals that inhabit the depths of the world's oceans certainly stand out...



1. STARGAZER

+ Stargazers bury themselves in the sand before leaping upwards to ambush prey. To assist their flytrap tendencies, they possess a large mouth and a big head. Some species also have a worm-shaped lure growing out of their mouths that wiggles to attract a potential lunch's attention. They grow between 18cm and 90cm.

2. ANGLERFISH

+ There are over 200 species of anglerfish, most of which live in the murky depths of the Atlantic and Antarctic oceans. They have huge heads and enormous crescent-shaped mouths packed with sharp, translucent teeth. Some anglerfish can reach a metre in length, though most are less than a foot.

3. GIANT ISOPOD

+ Giant isopods have been found between 550 to 7,020 feet down, though potentially live even deeper. In general, they measure between 7.5 and 14.2 inches but have been known to reach 2.5 feet. Despite their size, they're adapted to go without food for long periods of time. One giant isopod in Japan went five years without eating a morsel!

4. HIGHFIN LIZARDFISH

+ Otherwise known as Bathysaurus mollis, these bottom-dwelling fish inhabit the oceans below 1,600m in depth. They have flat heads, and curved and barbed teeth. Both features have evolved for the lizardfish to lie in wait before consuming its prey. They come in at around 78cm in length.

5. RATFISH

+ The ratfish is a primitive group of fish with skeletons composed of cartilage. The ratfish is found in all the world's oceans near the sea floor at depths of 300-2,000m. Their bodies taper to an exceptionally long threadlike tail. Together with their rodent-like teeth, designed for crushing the shells of their prey, it has earned them their 'ratfish' moniker.

IMAGE © THINKSTOCK

ABOVE The deep-sea fangfish has been spotted at depths of more than 5,000m

to 4°C. The salt in seawater ensures water rarely freezes in the deep sea – seawater freezes at around -1.8°C – but if it did, it'd merely float to the surface.

Deep-sea creatures manage their cold environs in several ways. Firstly, they move very slowly because the cold slows down their metabolism. Some also contain adapted enzymes to deal with the harsh environment, while many have been reported to feature high levels of unsaturated fats in their cell walls. This helps them to maintain the membrane fluidity in freezing cool depths of the ocean.

OXYGEN FUELLING

So animals like the anglerfish have adapted to pressure and temperature but how about stimulating the basic process of metabolism? In other words, how readily can it tap into oxygen? Pretty easily as it happens.

Much of the deep sea comprises adequate levels of oxygen because oxygen dissolves easier in cold water than warm. In fact, there are certain areas of the oceans that are so dense with oxygen that they sink to the bottom, creating what's termed 'thermohaline currents'. These travel around the planet, fuelling plant and animal life. However, there's a sort of 'oxygen no-man's land' at around 500m–1,000m, which is too deep to benefit from photosynthesis-derived oxygen and too shallow to enjoy oxygen from thermohaline currents. How life form exists and excels at these depths remains unknown.

FEEDING LIFE

Food is scarce in the deep sea, so many animals, including sea anemones, sponges and barnacles, simply wait for the food to sink to the sea floor. A shark, dolphin or whale could fuel hundreds of species for a long time.

There are also some more ingenious adaptations. Some mesopelagic species, for instance, have adapted to the low food supply with a behaviour called vertical migration. The lantern fish, for instance, will migrate from the depths to the food-rich surface under the cover of darkness at night. Then to avoid being eaten in daylight, they'll plunge back down.

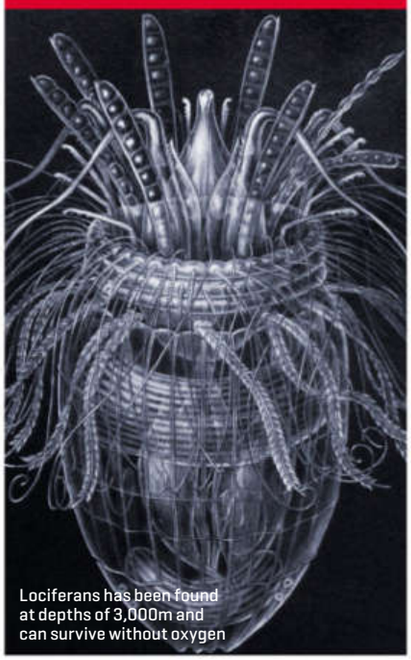
Deep-sea animals have also adapted in numerous other ways, including body colour, which acts as camouflage, and by living for many centuries, which counters the problem of slow reproduction rates due to the paucity of partners. Of course, with so much of the oceans undiscovered, you can be sure further adaptations will become clear as time passes. DS

FOOD IS SCARCE IN THE DEEP SEA, SO MANY ANIMALS SIMPLY WAIT FOR FOOD TO SINK TO THE SEA FLOOR

LIVING A LIFE WITHOUT ANY OXYGEN

Some parts of the sea could be perceived dead... but they're not

+ Most of the deep sea-floor has oxygen but, occasionally, there are exceptions. In deep basins where no circulation of water occurs, oxygen remains absent. One of these basins nestles at the base of the Mediterranean and is free from life...? Not quite. In 2010, researchers investigating depths of 3,000m discovered the first known animal to live continuously without oxygen. They're called Lociferans and are from an animal phylum discovered in 1983. How they survive and exist isn't fully known but it's clearly by anaerobic means (producing energy without oxygen).



Lociferans has been found at depths of 3,000m and can survive without oxygen

IMAGE © CAROLYN GAST, NATIONAL MUSEUM OF HISTORY

James Witts
Science journalist
+ James is a science and sports-science journalist based in Bristol. He's written for numerous science and sports publications around the world for 15 years. *@james_witts*

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THE WORLD'S FASTEST FISH!

The killer whale is hot on its heels, but nothing beats the spiky sailfish when it comes to all-out speed

WORDS BY **GRAHAM BARLOW**

Clocked at a staggering 68 miles per hour, while leaping out of the water, the sailfish is the undisputed speed king of the sea. Found in the warmer parts of all the world's oceans, sailfish are distinguished by the large sail-like fin that runs down their back. The fin is usually kept folded when swimming, but can be raised when the fish is frightened or excited, making it look much larger than it really is, perhaps in an effort to deter predators.

Like other members of the billfish group, which also contains the swordfish, marlin and spearfish, sailfish are predators, preying on smaller fish and squid. With their long bills that project forward like swords, these animals look like stabbing machines, but rather than trying to skewer smaller prey, they thrash their bills about as they swim through schools of fish, then return to eat any they've managed to stun.

The other billfish are fast, too: swordfish and marlin rank two and three, respectively, in the world's fastest fish list. What's amazing is that sailfish reach the same speed as the fastest land-based animal, the cheetah, yet water is 750 times denser than air, which makes their achievement even more impressive.

The exact reason why billfish, as a group, are such fast swimmers confounded scientists until fairly recently, as the fish seem to lack the required muscles for quick acceleration and maintaining ridiculous top speeds. The rapid acceleration of dolphins was equally puzzling to scientists for the same reasons. In 1936, British zoologist James Gray posited Gray's Paradox, after making an estimate of the amount of power that a dolphin could exert and found it insufficient to match the drag force of the water. He hypothesized that the dolphin's skin must have some kind of anti-drag ability that hadn't been discovered yet.

It wasn't until 2014 that a team of theoretical mechanical engineers at Northwestern University showed that to be a red herring. They proved Gray's Paradox to be false, based on its incorrect assumption that the drag force could never be greater than the muscle work required. In fact, it could be thanks to an 'energy cascade' caused by the fish undulating its body, which accounted for the high acceleration speed.

However the sailfish manages its incredible rapid acceleration and maximum speed, one thing is for sure – you don't want to be anywhere near that bill when it does. Many of their natural predators, like the great white and mako sharks, have been found with bills embedded in them, as have some fishermen!

GRAHAM BARLOW
Science writer
+ Graham has been a journalist for 20 years and has written for publications such as *Science Uncovered*, *LIfeHacker* and *TechRadar*. @gbarl

ABOVE Sailfish have the ability to change their colour instantly, usually adopting a light blue colour with yellow stripes to confuse their prey when hunting

IMAGE © THINKSTOCK

Newly-discovered species could lead to medical breakthroughs

Medicines using chemicals from marine organisms include drugs to fight cancer, HIV and malaria

AROUND 1,500 NEW SPECIES ARE FOUND EACH YEAR... WE THINK AROUND 500,000 TO 750,000 AQUATIC SPECIES ARE WAITING TO BE DISCOVERED

FINDING **NEMO**

How much marine life still hides within the oceans, waiting to be discovered?

WORDS BY **Andrew Westbrook**

Dr David Ebert has discovered 24 new species of shark

The Pacific Shark Research Center director has made many of his finds while exploring fish markets

IMAGES © ELLIOTT JESSUP AND THE CALIFORNIA ACADEMY OF SCIENCE

Science is simply common sense at its best," wrote English biologist Thomas Huxley in 1880. It's a statement that makes particular sense when considering the world's oceans and the life they may support. After all, with 70 percent of the planet covered by water, and much of that water not thoroughly investigated, common sense dictates there's plenty more marine life to be found.

Indeed, recent research suggests the majority of the oceans' species remain unknown, despite new discoveries being made at a rate of almost 1,500 a year.

"We think around 500,000 to 750,000 species are out there waiting to be discovered," explains Dr Jan Mees, vice-chair of the World Register of Marine Species, or WoRMS, a 'master list' that aims to detail all known marine species (see 'Taking the Register' box, right).

"The reason we keep discovering new species is simply because the ocean is huge, and vastly under-

TAKING THE REGISTER

How taxologists are compiling a 'master-list' of everything that's living in the oceans...

+ Aiming to provide an authoritative list of all marine organisms, the World Register of Marine Species, or WoRMS to its friends, got to work in 2008. Funded primarily by the EU and hosted by the Flanders Marine Institute, the online inventory (www.marinespecies.org) now includes more than 230,000 species.

"We need this tool to advance ecological research," explains WoRMS vice-chair Dr Jan Mees. "We've created a global community of more than 200 taxonomic editors, professional biologists specialised in certain animals or plants. In the first decade they've added a lot of historical information – this is now near completion. We think that 95 percent of all species ever described are now in the list."

Merging scores of global databases, while adding new data, WoRMS editors found 424,000 species, but discovered that about 45 percent of them were duplicates. In 2014, some 1,451 new-to-science species were also added to the 'master-list' – an average of more than four a day.

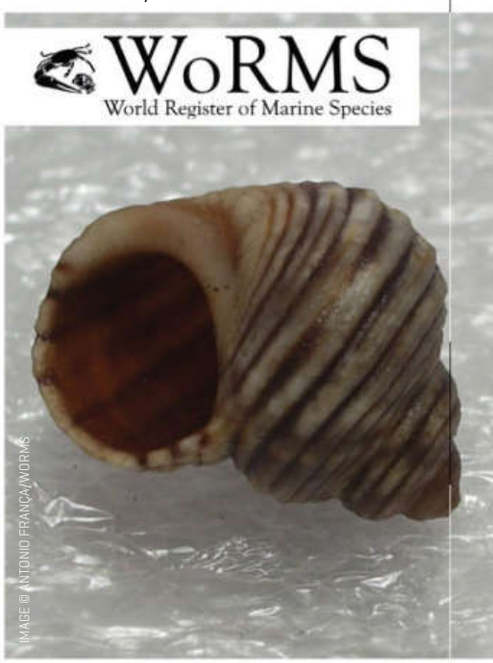


IMAGE © ANTONIO FRANÇA/WORMS

ABOVE King of confusion: editors discovered the rough periwinkle sea snail had been listed 113 times under different names.

Only about 18,000 of known marine species are fish

The majority are kelp, seaweeds, plants, bacteria, viruses, fungi and single-cell organisms

explored and under-sampled," Dr Mees continues. "There are many places we haven't looked yet. Another issue is that many marine species are rare and difficult to observe and collect. And there's the issue of 'cryptic diversity': species that cannot be distinguished by examining their morphology, but prove to be several distinct species when examined with novel genetic techniques. So, even in well-explored parts of the world, we still find new species."

HUMPBACK DISCOVERY

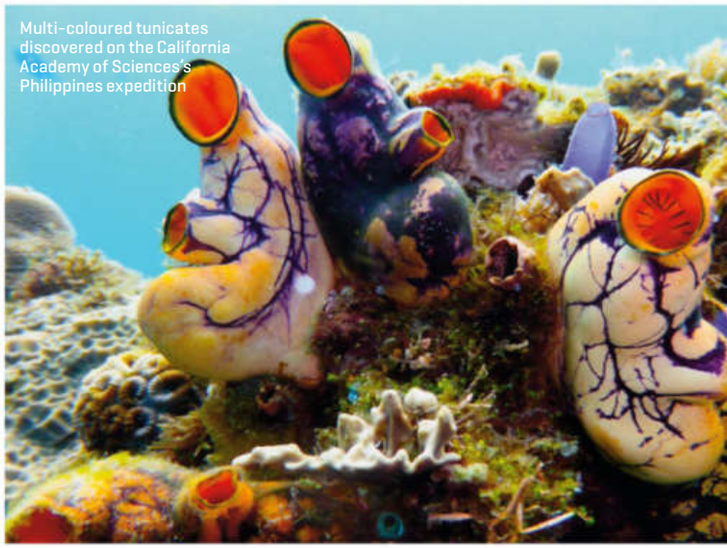
In total, 1,451 new species were added to WoRMS last year. They included the Australian humpback dolphin – a shy, medium-sized cetacean found off northern Australia – and the Chlamydoselachus Africana, a frilled shark species found off Namibia.

The vast majority of new discoveries are far smaller. The tiny Areospora rohanae, for example, is a new genus and species of parasite. First noticed by Chilean fisheries workers, it invades and causes lesions on the king crab. The taxonomist named it after his daughter, Rohana. In Puerto Rico, meanwhile, biologists found a new species of mite on a coral reef 70m deep. They proceeded to name it Litarachna lopezae, in honour of Puerto Rican singer Jennifer Lopez, after supposedly enjoying her music while on the research trip. Also added to the register was new giant jellyfish Keesingia gigas, named in honour of biologist John Keesing. Unusually tentacle-free, it's thought to cause Irukandji syndrome, a condition that can lead to heart failure in humans. About the size of a human arm, the Australian jellyfish earned the gigas name due to other Irukandji jellies being closer in size to a fingertip.

The recent favourite of Dr Mees, a Mysida specialist, however, is the stargazer mysid or Mysidopsis zsilaveczi. "It was named," he explains, "in honour of the diver Guido Zsilavicz, who first saw it, brought it to the surface and sent it to the university for further study – a true citizen-scientist!" The South African shrimp was also given a common name to highlight the pigmentation pattern of its eyes, which makes it look as if it's always looking skyward.

BULK FIND

WoRMS, however, only records species that have gone through the long process of being recognised, analysed and described. One man at the coalface of discovery is Dr Terry Gosliner, senior curator of invertebrate zoology at the California Academy of Sciences. He was also the principal investigator on the Academy's 2015



Multi-coloured tunicates discovered on the California Academy of Sciences's Philippines expedition

The stargazer mysid, a South African shrimp discovered by citizen-scientist Guido Zsilavecz

ANIMALS AT RISK

While new species are discovered every day, thousands we already know about are deemed to face the risk of extinction. Here are some of the species unfortunate enough to make it onto the International Union for the Conservation of Nature (IUCN) Red List

HAWKSBILL TURTLE

+ Hawksbills are critically endangered, having decreased by 80 percent in three generations. The primary reason is their distinctive patterned shells. Millions were killed for their shells in the last century, while the trade continues in parts of the Americas and Asia.

VAQUITA

+ This endangered porpoise was only discovered in 1958, but now numbers less than 250. Found only in the Gulf of California, the 1.5m-vaquita, which is Spanish for 'little cow', is the world's smallest cetacean. Numbers are believed to be plummeting due to illegal fishing with gillnets.

BLUE WHALE

+ Weighing up to 200 tons and with a heart the size of a car, the blue whale is the largest animal on the planet. It's also endangered with a population of 10,000 to 25,000. Hunters killed about 360,000 before protection was introduced by the International Whaling Commission in 1966.

Over 1,000 fish species have been found since 2008

That includes 122 new sharks and rays, 131 new gobies and one new barracuda

IMAGE © GARY WILLIAMS AND THE CALIFORNIA ACADEMY OF SCIENCES

IMAGE © GARY WILLIAMS AND THE CALIFORNIA ACADEMY OF SCIENCES

New plant and aquatic animal life is being found all the time

IMAGE © GUIDO ZSILAVECZ/WORMS

IMAGE © ROBERT PITMAN/WORMS

The Australian humpback dolphin was only discovered and named as recently as 2014

expedition to the Philippines, during which more than 100 new species were collected, such as a white-coloured nudibranch from the Halgerda genus. Exploring the so-called 'twilight zone' – 50–150m deep – they discovered a diverse area of mesophotic reefs where animals live in partial darkness. "Complex rebreathers with sophisticated computers and motorised underwater scooters are all required," explains Dr Gosliner.

"One of the most important things we discovered," he adds, "is that many of the species found in the twilight zone have close relatives in shallow water. The twilight zone has been colonized many times. This is very different from the deep sea, below 1,000m, where almost no species have close relatives in shallow water.

"These discoveries are critically important to conservation of life in the ocean and to our very own survival. We can only know how to effectively preserve life in the ocean when we know what species there are, how they are distributed and how they are related to each other."

But are there still more to be found? "A whole lot more," replies Dr Gosliner. "We know so little about the diversity of life on our planet. We estimate only 10 percent of life on our planet has been discovered and documented by scientists."

GREAT WHITE SHARK

+ Despite getting so much attention, few hard facts are known about the great white. One assumption is that numbers are dwindling – it's been listed as vulnerable since 1996. People – through fishing, paranoid media campaigns and the curio trade – are seen as its biggest threat.

HAWAIIAN MONK SEAL

+ Despite benefiting from a conservation programme, the only seal endemic to Hawaii is still endangered. Numbering about 1,200, threats range from changes in oceanographic conditions impacting on food supplies, to chemical contaminants remaining from World War II military bases.

BLUEFIN TUNA

+ It might be fast and grow up to 2.5m, but it's also too popular a meal. All three species of bluefin – the Southern, Atlantic and Pacific –are considered at risk, but especially the critically endangered Southern, with its spawning stock biomass dropping 85 percent since the 1970s.

HUMPHEAD WRASSE

+ One of the few reef fish protected by name, the humphead grows up to 2m long. It's listed as endangered due to its population having halved in 30 years. The primary cause is the lucrative live fish trade, of which the humphead is one of the most sought-after.

LEATHERBACK TURTLE

+ The largest sea turtle, weighing in at 650kg, the once critically endangered leatherback could become a conservation success story. The number of females had plummeted by 40 percent in three generations, but researchers believe overall numbers will be rising again by 2030.

RANDOM MATTER

Stethacanthus resembled a modern shark

That is apart from the ironing-board-shaped dorsal fin near its head

PREHISTORIC MARINE LIFE

Millions of years ago, sea life was bigger, faster and more brutal than today's aquatic animals

WORDS BY **James Witts**

In 2010, 163 years after her death, the Royal Society included Mary Anning on a list of the 10 British women who have most influenced the history of science. Anning was born and died in Lyme Regis, one of the most active paleontological regions of the UK. Here, Mary and her dog Tray made a name for themselves thanks to an extraordinary number of scientifically important discoveries, including the first ichthyosaur skeleton to be correctly identified and finding the first two plesiosaurs.

"Mary Anning is probably the most important unsung (or inadequately sung) collecting force in the history of paleontology," noted paleontologist Stephen Gould has said. And he's right. Anning's discoveries, coupled with Darwin's theories on evolution, forged a new world fascinated by prehistoric sea creatures.

THE ICHTHYOSAUR

This was a world inhabited by marine life bigger and more 'unique-looking' than the aquatic organisms of the modern day, much of it discovered in Anning's home town of Lyme Regis. In fact, the first complete ichthyosaur skull was found by Joseph Anning, Mary's brother, in Dorset in 1811. Ichthyosaurs now populate museums all around the world and were prevalent throughout the Mesozoic era, first appearing around 250 million years ago.

Similar looking to dolphins, on average they grew to around two to four metres, though species are estimated to have reached 15m. They were carnivorous, their pointed snouts adapted to grab smaller animals. Their huge eyes – the largest documented compared to body size of any vertebrate – intimates they either hunted at night or at great depths. They were wiped out around 25 millions years before an asteroid slammed into Earth and finished off the dinosaurs. Despite reams of research, why remains unknown.

The ichthyosaur's cuteness wasn't matched by the shark that dwarfs them all. We cover sharks in detail from page 68, specifically the great white, but the current crop are mere plankton compared to the Megalodon. Fossil remains suggest this enormous shark reached a maximum length of 18m-20m. That's around three times

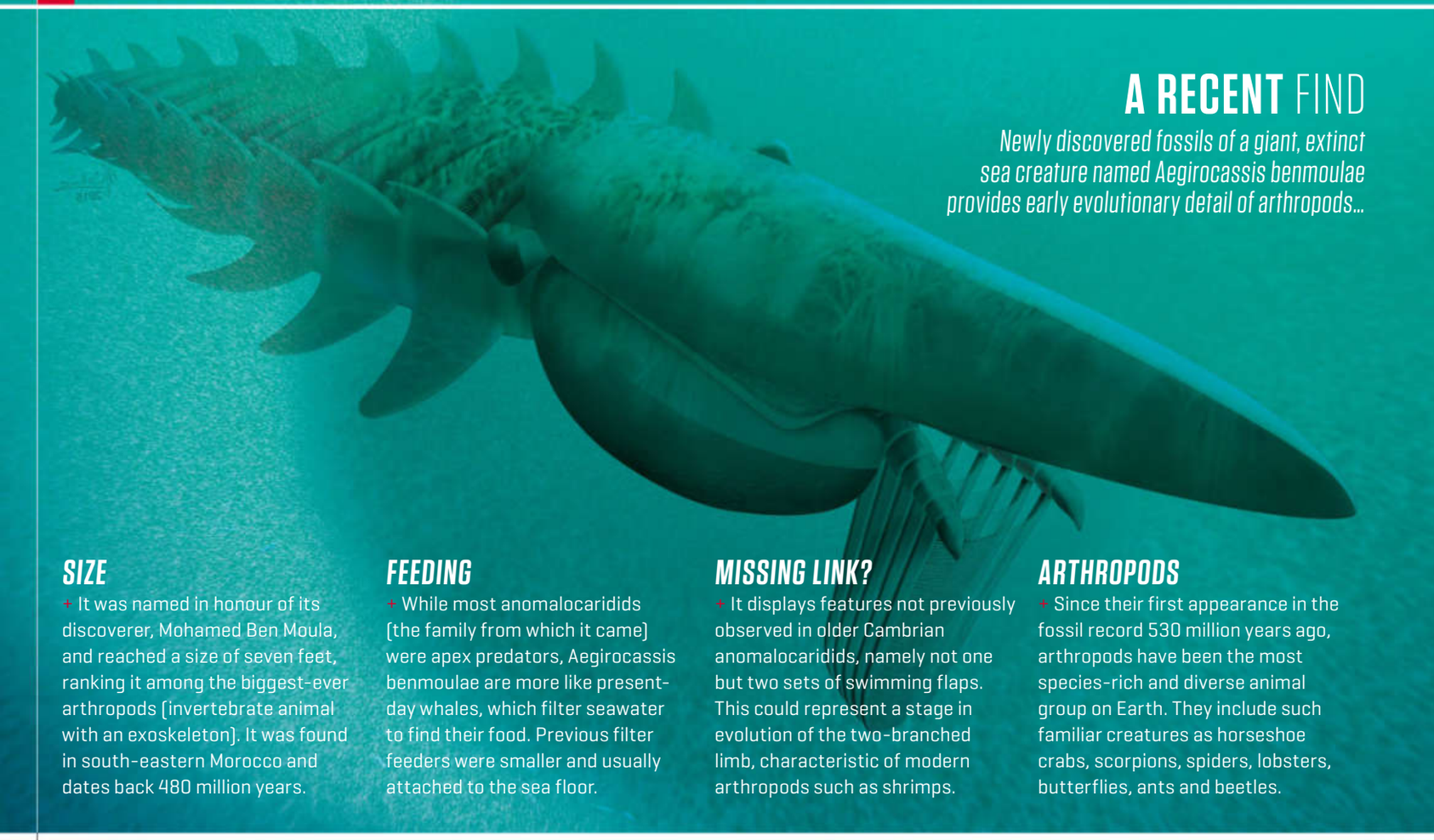
ICHTHYOSAURS WERE WIPED OUT AROUND 25 MILLION YEARS BEFORE AN ASTEROID SLAMMED INTO EARTH AND FINISHED OFF THE DINOSAURS

Parapuzosia was the world's largest ammonite

It lived during the late cretaceous period and measured 1.8km in diameter

Xiphactinus could leap out of the seawater

The 6m-long fish didn't do it for food, though, but to dislodge parasites from its skin



A RECENT FIND

Newly discovered fossils of a giant, extinct sea creature named Aegirocassis benmoulae provides early evolutionary detail of arthropods...

SIZE

+ It was named in honour of its discoverer, Mohamed Ben Moula, and reached a size of seven feet, ranking it among the biggest-ever arthropods (invertebrate animal with an exoskeleton). It was found in south-eastern Morocco and dates back 480 million years.

FEEDING

+ While most anomalocaridids (the family from which it came) were apex predators, Aegirocassis benmoulae are more like present-day whales, which filter seawater to find their food. Previous filter feeders were smaller and usually attached to the sea floor.

MISSING LINK?

+ It displays features not previously observed in older Cambrian anomalocaridids, namely not one but two sets of swimming flaps. This could represent a stage in evolution of the two-branched limb, characteristic of modern arthropods such as shrimps.

ARTHROPODS

+ Since their first appearance in the fossil record 530 million years ago, arthropods have been the most species-rich and diverse animal group on Earth. They include such familiar creatures as horseshoe crabs, scorpions, spiders, lobsters, butterflies, ants and beetles.

LEFT Like today's sea animals, prehistoric creatures were a mix of carnivores and herbivores

BELOW Fossil records of ichthyosaurs populate museums all around the world

IMAGE © NATURAL HISTORY MUSEUM

larger than great whites. Some of the teeth discovered from the Megalodon measured over 17cm. It roamed the seas from around 28 million years ago until around 1.6 million years ago when they were wiped out during the Pleistocene extinction.

Megalodon fossils have been discovered all around the world, including Europe, Africa and North America. Not surprisingly, they swam at the top of the aquatic food chain, their diets including dolphins and whales. Its killing technique of choice purportedly involved the Megalodon shooting up from the depths like a rocket before slamming its nose into the belly of a whale that nestled near the surface. The idea's based upon fossil evidence of whale vertebrae that showed compression damage, seemingly caused from a significant blow from below.

But it's the cretaceous (145 to 65 million yeas ago) oceans that are deemed the most lethal of all time thanks to the huge amount of dangerous predators that populated the waters. An example is the story of the Hesperonis. The bird spent much of its time perched on rocky ledges above the sea. Sadly for the Hesperonis, it was frequently picked off by small mosasaurs like Halisaurus, who waited in caves beneath the ledges for a Hesperonis to dive in.

Mind you, these mosasaurs were small fry compared to the Giant Mosasaurs that gave the Megalodon a run for its money, coming in at 17m. Size was clearly important during the cretaceous period as Elasmosaurus – a type of plesiosaurs – stretched to 15m long, its huge neck sneaking up on unsuspecting shoals of fish.

JURASSIC DANGER

The Jurassic period also contained its fair share of deadly sea animals. Sharks like Hybodus and the crocodilian Metriorhynchus were dominant beasts, but were mere small fry compared to the Liopleurodon, which is estimated to have reached lengths of nearly 25m, though more conservative estimates are half that figure. Its fossils have

Halisaurus had extra teeth called pterygoid teeth

It used these to grip its prey while its jaw then moved forward to swallow

The mighty shark Megalodon's teeth measured over 17cm

been found in numerous marine deposits throughout Europe. Four huge paddle-shaped limbs propelled it through dangerous waters and its 3m-wide mouth contained teeth twice as long as the Tyrannosaurus.

Recent studies on the skull of Liopleurodon have shown that it could sample the water through its nostrils. This allowed it to ascertain where certain smells came from. If it swam along with its mouth open, water would pass straight up into scoop-shaped nostril openings in the roof of its mouth, which would then pass out through nasal openings in front of the eyes. This flowing of water would alert it to any prey in the vicinity.

Of course, fish that appeared in prehistoric times didn't all die out. According to fossil records, hagfish have existed for over 300 million years. That means they were already stroking their aged whiskers by the time dinosaurs roamed the world. Hagfish – otherwise known as 'slime eels' – are found in relatively deep waters. Rather bizarrely they have a skull but lack a spine, and they're graced with two brains.

Their eating habits involve late-night feeding on the carcasses of large animals, like fish and cetaceans, which drift down to the bottom of the sea. Their slime repellent means they're virtually predator-free, though inshore hagfish is a delicacy in Korea – as is the slime, which is used in a similar manner to egg whites.

A fish popular with the upper echelons is the sturgeon, which has become well-known for providing caviar. They've populated the oceans since the Jurassic period and can grow to nearly 6m. And then there's the Alligator Gar. They're one of the oldest fish around today, being traced back to the cretaceous period. This thick-scaled predator is found in the southern USA and east of Mexico; in fact, it's the largest freshwater fish in North America, though it sometimes drifts off into the sea. It can reach 4m in length and weigh up to 200kg. They're ambush predators, those long jaws and the double row of sharp teeth feeding off small mammals and marine life. Despite the occasional human bite, there have been no confirmed deaths due to a Gar bite.

Whether in fossil form or the flesh, prehistoric sea creatures astound. Trawl the world's waters and you'll come across a living, breathing prehistoric creature. Or let your imagination fill in the gaps and simply visit a museum. DS

James Witts
Science Writer
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FOUR POWERFUL PREHISTORIC CREATURES

This quartet of carnivores dominated the oceans many millions of years ago...

NOTHOSAURUS

+ Nothosaurus were 4m long and were fearsome hunters. A mouthful of sharp, outward-pointing teeth suggests it lived on a diet of squid and fish. It's believed that Nothosaurs were related to pliosaurs, another variety of deep sea predators. Fossil evidence suggests that they lived over 200 million years ago.

TYLOSAURUS

+ Tylosaurus was a species of mosasaur and reached more than 15m in length. It was a meat eater with a diverse diet, its stomach remains showing signs of fish, sharks and even some flightless birds. They lived during the late cretaceous period in the seas that covered North America.

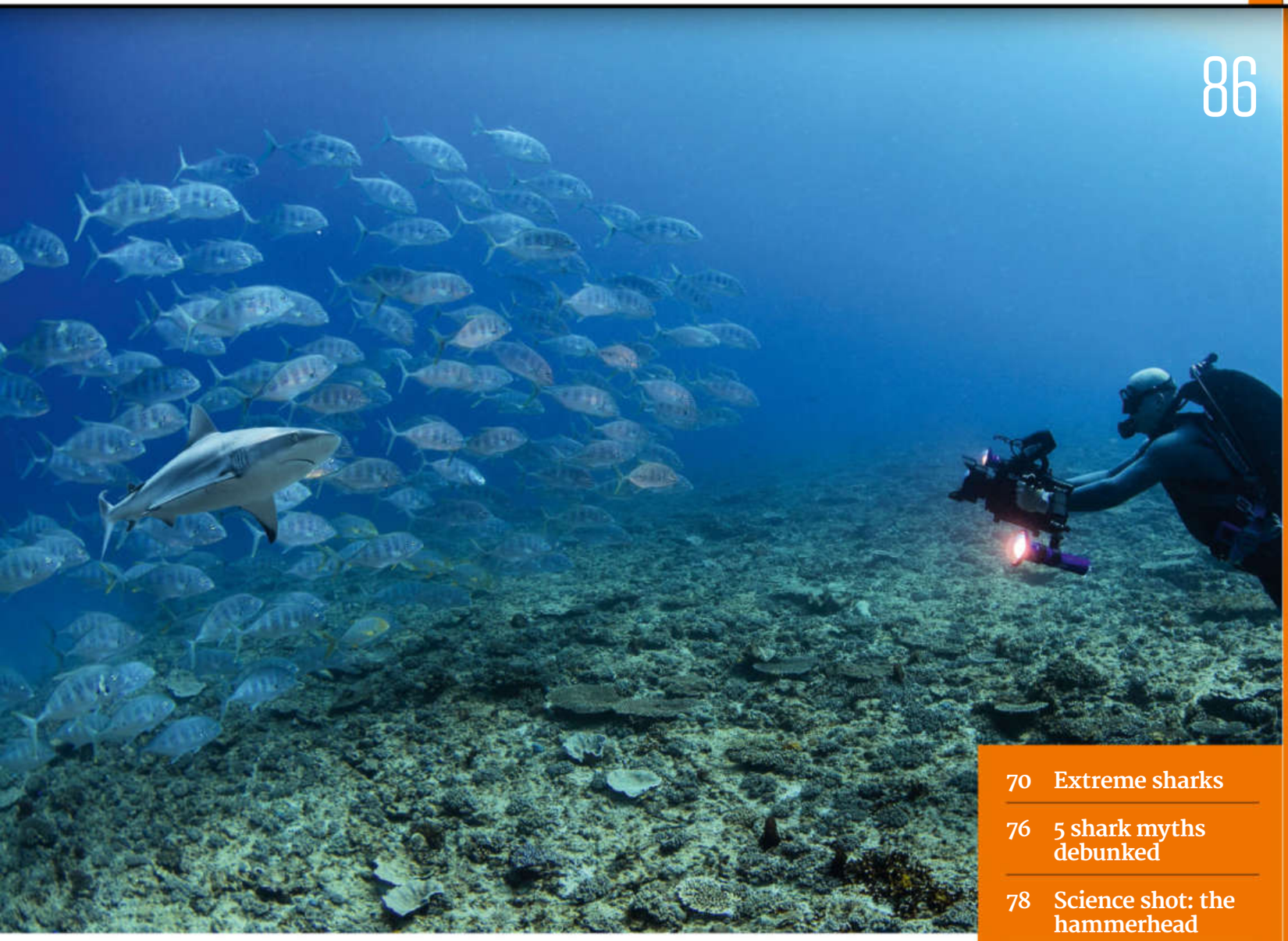
BASILOSAURUS

+ Basilosaurus is thought to have grown up to 18m long, bigger than any known mosasaur. Despite its size it had a weak skeletal construction that restricted it to upper surface waters. It lived about 50 million years ago.

DAKOSAURUS

+ Daokosaurus' body was a mix between reptilian and fish, and lived during the late Jurassic and early cretaceous periods. It could reach a length of 5m and its mouth was packed with rows of sharp, serrated teeth. It was first discovered in Germany back in 1856, but fossil specimens since have shown up in England, Argentina and Russia.

SHARKS



"THE GREAT WHITE CAN DETECT ONE DROP OF BLOOD IN TEN MILLION DROPS OF WATER"

PAGE 80

EXTREME SHARKS

From the biggest to the slowest, meet the sharks who live on the edge

WORDS BY **Ian Evenden**

THE MOST EATEN BLACKTIP SHARK

'Height of cuisine' threatens its existence

Pity the blacktip shark. Along with its relative, the sandbar shark, the blacktip is one of the most caught sharks in the Atlantic Ocean and is being nudged toward threatened status as a result.

In some cases the whole of the shark is taken by fishermen, and its meat, oil and skin are used by humans. Some unfortunate sharks, however, are 'finned' – their fins are cut off and the rest of the shark, still alive, is thrown back into the water where, unable to move, it either asphyxiates or is taken by predators.

The reason for this is soup. Shark fin soup is a popular dish in China and, although the fins have no flavour of their own, they add texture (chewy and gelatinous) to a dish often served on special occasions or to flaunt social status.

By not carrying the weight of the sharks' bodies back to port, the fishermen can maximise their profits from supplying the soup trade.

The highest estimate for the number of sharks killed in this way each year is 73 million. And it's not just blacktips and sandbars, but hammerheads, threshers and even great whites that are butchered.

Laws to prevent finning have been passed in a number of countries, including Australia, Canada, Taiwan, the USA and the EU, but the removal of so many apex predators from the seas affects not just the sharks themselves. It can also have a detrimental effect on entire ecosystems.

THE HIGHEST ESTIMATE FOR THE NUMBER OF SHARKS KILLED BY FINNING EACH YEAR IS A STAGGERING 73 MILLION

'Finning' is a horrendous way to die as blacktips are asphyxiated when dumped back in the sea

COLDEST HABITAT SALMON SHARK

The Alaskan shark that batters salmon

Salmon sharks are found in the north Pacific

AS A RELATIVE OF THE GREAT WHITE, IT HAS THE SAME ABILITY TO WARM PARTS OF ITS BODY ABOVE AMBIENT WATER TEMPERATURE

Think of sharks and you might imagine the azure waters of Mexico, Australia or South Africa rather than Alaska, Tunguska and Japan, but that's where the salmon shark is found. A purely northern-Pacific species, it can be found as far south as California while its northerly range almost touches the Arctic Circle.

In Alaska, it frequents Prince William Sound for the annual salmon run, when Pacific salmon return from the sea to the rivers they were born in to spawn and die. The salmon shark assists the salmon with the latter before they've had time to achieve the former, consuming them before they can swim up the rivers into fresh water, where it can't follow.

As a relative of the great white, the salmon shark has the same ability to warm parts of its body above the ambient water temperature, allowing it to move quickly in the cold water.

Salmon sharks exhibit an unusual split between their eastern and western populations. Western Pacific sharks, around the coast of the US, show more males than females, while on the eastern shores of the ocean, around Japan, there are more females than males.

One hypothesis as to why this should be is down to Japanese fishermen harvesting the fins of male salmon sharks for use in traditional medicine. The sharks have been documented moving from one side of the ocean to the other, however, so they are still able to breed.

Their future looks relatively secure as no commercial fishing for salmon sharks exists. However, they are occasionally caught in commercial salmon gillnet fisheries where they're usually discarded.

The wobbegong lays motionless on the seabed

It sits there quietly… but can strike its prey in 25 milliseconds

THE SLOWEST GREENLAND SHARK

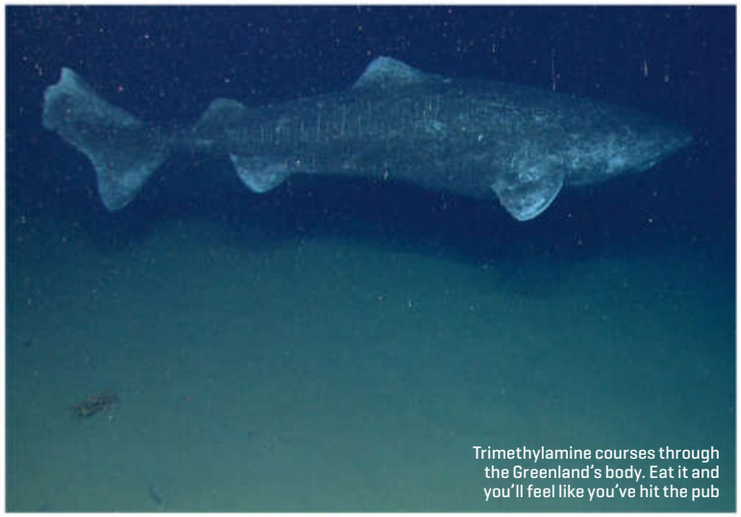
Its slow movements increase longevity

With a lifespan of up to 200 years, the Greenland shark has time to take it easy. It swims at about half the speed of a seal through the cold, deep waters it prefers, and is often blind thanks to eye parasites, meaning scientists were for some time baffled by how the shark managed to catch prey.

It transpires that it could be catching them by surprise. According to a hypothesis put forward by Tokyo's National Institute of Polar Research, the shark's slow movements and blackish-brown skin allow it to sneak up on seals who sleep in the water in the Arctic to avoid polar bears.

The remains of bears, moose, horses and reindeer have also been found in Greenland sharks' stomachs but its main diet is fish. Greenland sharks are generally found around the coasts of Greenland, Canada and northern Europe, but have been caught as far south as the Gulf of Mexico. Much about the life of this shark remains unknown, as for something the size of a great white it's a very secretive creature, and it's not often deliberately caught by humans as its flesh is toxic.

Eat a Greenland shark and you'll experience symptoms similar to being drunk thanks to the presence of trimethylamine oxide in its body. This compound, which gives rotting seafood its distinctive smell, is common in deep-sea fish as it may help counteract the adverse effects water pressure has on proteins. However, it does humans no good whatsoever.



Trimethylamine courses through the Greenland's body. Eat it and you'll feel like you've hit the pub

THE REMAINS OF BEARS, MOOSE, HORSES AND REINDEER HAVE BEEN FOUND IN GREENLANDS' STOMACHS BUT THEIR MAIN DIET IS FISH

IMAGE © THINKSTOCK

ABOVE Despite the low quality of its meat, longfin and shortfin mako numbers are estimated to have plummeted by up to 40% since the 1980s

THE FASTEST MAKO SHARK

Thirteen rows of teeth… moving at speed

Capable of swimming at 46mph and leaping 3m into the air, mako sharks can lay claim to the title of most athletic shark in the seas.

Both the longfin and shortfin forms are found all over the world, preferring warmer waters down to about 150m and feeding on fish, other sharks, seabirds, squid and whatever else is unlucky enough to find its way into a mouth packed with up to 13 rows of long, thin teeth that remain visible when the shark has its mouth closed.

The great speed and leaping ability shown, particularly by the shortfin mako, make it a favourite fish for sport fishermen, although it isn't commercially fished due to the low quality of its meat. The mako is, however, found in fishing nets as bycatch, possibly due to it targeting the trapped fish as prey and getting stuck. As a result, mako numbers are estimated to have dropped 40% since the 1980s.

When hunting, the mako seems not to use the electro-receptive sense seen in other sharks such as the great white and the hammerhead. Tests with a decoy designed to emit electrical signals showed no preference, but longfin makos are attracted to lights in the water, suggesting it uses its hearing, eyesight and sense of smell to target its prey.

LONGFIN MAKOS ARE ATTRACTED TO LIGHTS, SUGGESTING IT USES ITS HEARING, EYESIGHT AND SENSE OF SMELL TO TARGET ITS PREY

THE BIGGEST TAIL
THRESHER SHARK
Its name derives from its lethal weapon

An open-ocean shark that lives above 500m, the three species of thresher shark are marked out by their enormous tail fins, which can be as long as the rest of the shark's body.

Those tails, referred to as caudal fins, are used as a weapon to stun fish. A report published in the journal PLOS ONE (Oliver et al, 2013) describes the behaviour: 'Strikes began with a shark adducting [moving toward the middle of the body] its pectoral fins, a manoeuvre that changed the shark's pitch, promoting its posterior region to lift rapidly… The shark's tail then accelerated in a whip as it travelled overhead the length of its body to the tip of its snout. The final prey item collection phase was typically characterised by a thresher shark turning 180° and collecting dead and/or stunned sardines.'

This whipping forward of the tail at speeds of up to 50mph can create so much force that dissolved gas is forced out of the water, causing bubbles to form.

Unfortunately, this taste for sardines brings the thresher shark into contact with human fishermen – they are often found attached to fishing lines by their tails after whipping at the bait.

As well as being farmed as a sport fish, threshers are hunted for their meat, skins and liver oil, which is thought to aid the healing of wounds. All three thresher sharks are classified as 'vulnerable' by the International Union for the Conservation of Nature.

THE WHIPPING FORWARD OF THE TAIL AT 50MPH CAN CREATE SO MUCH FORCE THAT DISSOLVED GAS IS FORCED OUT OF THE WATER

The thresher shark's tail can help it reach speeds of 50mph. That's enough to stun its victims

THE BIGGEST NOSE
CARPENTER SHARK (SAWFISH)
An industrial nose to dig out crustaceans

The carpenter shark poses no risk to humans

IMAGE © THINKSTOCK

HIGHLY ELECTRO-SENSITIVE IN A SIMILAR WAY TO SHARKS' AMPULLAE OF LORENZINI, IT PLAYS NO PART IN EATING THE PREY

Carpenter sharks aren't true sharks. They're a branch of the ray subclass, closely related to sharks and are the only member of their family living today. They are also truly unbelievable to look at, with a long rostrum extending from above their mouths, studded with teeth to give them their other common name: sawfish.

Sawfish are spread across the Pacific, the Atlantic coasts and even into the Mediterranean. All species are critically endangered – down to as much as 10% of their historic population levels – as the coastal lagoon and river estuaries they call home are destroyed and fishermen take large numbers of them for food, liver oil and the £500 price a sawfish rostrum can fetch at a market. International trade in the creatures has been banned since 2007.

The sawfish uses its rostrum to dig up crustaceans

to eat as well as to detect their movements. It's highly electro-sensitive in a similar way to sharks' ampullae of Lorenzini, but plays no part in actually eating the prey – as with all rays, the sawfish's mouth is on its underside.

The carpenter shark is a gentle, nocturnal creature that poses no risk to humans unless attacked. They reproduce slowly, giving birth to live young whose rostrum is initially soft and encased in a sheath to protect the mother during the process. The sheath falls off as the rostrum hardens and the baby sawfish goes off to hunt on its own.

STRANGEST-LOOKING GOBLIN SHARK

A little-studied, unique-looking goblin

ABOVE Little is known about the rarely-spotted goblin shark, partly due to them living in 1,000m-plus deep waters

The goblin shark is a rare deep sea shark with an ancient lineage dating back some 125 million years. It certainly looks primordial, with its pinkish skin, protruding teeth and long, flattened snout, but it's what goes on below the nose that's truly horrifying.

Goblin sharks can extend their jaws, with over 30 rows of teeth, almost to the end of their snouts to snatch fish out of the dark waters they inhabit. Always found deeper than 100m (the record is 1,300m), they live in a world where little sunlight penetrates and the fish are strange, often white or silvered or even bioluminescent. They swim slowly, catching food via a pair of elastic ligaments that thrust their jaws forward to consume a passing meal.

Because of its deep-water habitat, the goblin shark is little studied, it rarely comes into contact with humans and a pregnant female has never been seen. We don't even know how big they grow, although males of around 2.6m have been captured. Attempts to keep goblin sharks in captivity for study have ended with the specimen dying after a week. Genetic testing suggests goblin sharks are the most primitive form of the Lamniformes, a family of sharks including the thresher and great white. It's not thought to be threatened by human activity, so could yet add a few more million years to its family tree.

GOBLIN SHARKS CAN EXTEND THEIR JAWS, WITH OVER 30 ROWS OF TEETH, ALMOST TO THE END OF THEIR SNOUTS TO CATCH FISH

MOST DANGEROUS TO HUMANS BULL SHARK

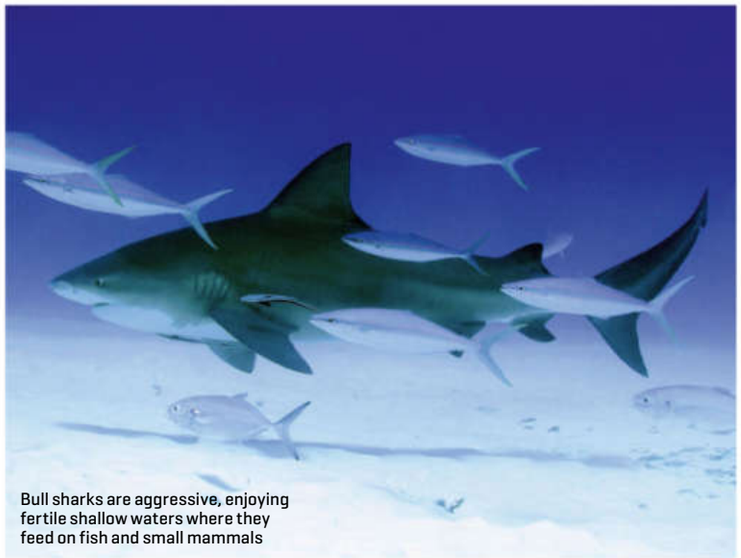
Salt regulation's key to its versatility

Sharks live in the sea. We know that. Bull sharks, however, have a habit of swimming up rivers into fresh water, meaning they come into contact with more humans than those in the oceans.

For any other saltwater fish, a trip into fresh water would be fatal. But the bull shark is able to regulate its salinity using their liver, kidneys, gills (which govern the salt going into the body) and rectal glands to adjust levels of salt and urea in its blood. The kidneys remove more urea and much less salt, which would be excreted through the rectal gland, from the shark's bloodstream, allowing it to tolerate the new environment. Essentially, a bull shark in fresh water is still salty on the inside.

Bull sharks have been found in Lake Nicaragua (65 miles inland from the Caribbean Sea, where its drainage river empties), 600 miles up the Mississippi river in Illinois and over 1,000 miles up the Amazon. The bull shark is aggressive and likes shallow waters where it finds the fish and small mammals it likes to eat by bumping into them and giving them a test bite. This is where it comes into contact with humans, biting bathers in the Ganges and rivers in Australia. Bull sharks breed in the brackish water of river mouths and coastal lagoons, and the ability to move between water types is more pronounced in young sharks. Still, you're 50,000 times more likely to drown than be killed by a shark, so bull sharks are no reason to be afraid of getting back in the water.

BULL SHARKS HAVE BEEN FOUND IN LAKE NICARAGUA, 600 MILES UP THE MISSISSIPPI AND OVER 1,000 MILES UP THE AMAZON



Bull sharks are aggressive, enjoying fertile shallow waters where they feed on fish and small mammals

IMAGE © THINKSTOCK

THE HEAVIEST WHALE SHARK

The biggest shark is also the most docile

Divers have been known to hop on and hitch a ride with whale sharks, though this is discouraged

IMAGE © THINKSTOCK

THE HEAVIEST WHALE SHARK DISCOVERED SO FAR WAS CAPTURED OFF THE COAST OF PAKISTAN AND WEIGHED 21 TONS

The biggest fish alive today, and the largest animal that's not a whale, the whale shark is a peaceful, slow-moving filter feeder that's a million miles away from the popular perception of sharks as merciless hunters.

The heaviest whale shark discovered so far was captured off the coast of Pakistan in 1947 and weighed more than 21 tons. That specimen was 12.6m long, but tales abound of larger whale sharks out there – they just haven't been weighed yet.

The sharks reach this great size by hoovering up vast quantities of plankton, krill and small fish with a mouth that can extend to 1.5m wide. Inside its mouth are up to 350 rows of small teeth, and 10 filter pads that strain tiny creatures from the water that passes over them as the shark swims with its mouth open. It can also pump water over the filters and out of its gills by taking gulps because it targets shoals of fish or other life.

If you're too big to eat, the whale shark will largely ignore you. Divers have been known to grab on and hitch a ride with the giant, although this is discouraged by conservationists.

Living up to 100 years, further details of the whale shark's life remain sketchy. Its breeding has never been observed, although it is known to give birth to live young, and while it is thought to migrate in search of food and mates, the world's biggest fish keeps some secrets for itself.

Likewise, there is currently no reliable estimate of the global whale shark population. However, the species is considered vulnerable by the International Union for Conservation of Nature because of its long lifespan and late maturation.

THE BIGGEST TEETH MEGALODON

A jaw-crushing force of 20 tons…

Huge fossil teeth on the ocean floor were the first clue that a giant shark had once lived in our oceans. Measuring over 180mm, the teeth are triangular and serrated – clearly the weapons of a killer – but the rest of the animal was nowhere to be found. Shark skeletons are largely made of cartilage, a softer material than bone, and this doesn't fossilise well. Megalodon (the name means 'big tooth') is known only from its spectacular teeth and a few preserved spinal columns, but this is enough to tell us a lot about the creature.

Megalodon lived from 15.9 to 2.6 million years ago, and was found in warm, deep waters across the world. It grew up to 20 metres – three times longer than a great white – and ate anything that crossed its path, from whales to giant sea turtles to unfortunate fish. The scars from its huge teeth are seen on fossil bones of whales – proof of a huge biting force that has been estimated by researchers in Sydney to be in the region of 20 tons. Compare that to 2 tons for a great white and an estimated 3.1 tons for a Tyrannosaurus rex.

Don't be too afraid about getting into the water, though: Megalodon is well and truly extinct, despite spoof documentaries and far-out theories of a relict population hiding in the oceans.

The climate began to cool around 15 million years ago, leading to lower sea levels as large volumes of water were taken up in glaciers and fewer shallow warm areas for young Megalodon to live safely. The closure of the gap between North and South America 2.5 million years ago also led to a decrease in the number of large whale species, which meant less food for the Megalodon. Megalodon was too large to exist without a constant supply of dinner, and the giant was driven to extinction.

MEGALODON LIVED FROM 15.9 MILLION TO 2.6 MILLION YEARS AGO. IT WAS FOUND IN WARM, DEEP WATERS ACROSS THE WORLD

The Megalodon grew up to 20m and consumed anything that crossed its path

IMAGE © THINKSTOCK

RANDOM MATTER

The assfish is probably *not* talking out of its…

It has the smallest brain-to-bodyweight ratio of all vertebrates, which is often a sign of intelligence

5 Shark myths debunked

Sharks have a certain persona, much of it cultivated by Benchley and Spielberg. But how much is simply a fishy tale?

WORDS BY **Ian Evenden**

1. SHARKS ARE BORN WITH LOTS OF TEETH

A shark will never run out of teeth, as teeth that fall out will be replaced, but this isn't the same as being born with thousands of teeth already in the mouth. Unlike humans, who have two sets of teeth that are fixed firmly into the jaws by roots and sockets in a single row, shark teeth are embedded in soft tissue. Thanks to a shark's enthusiastic feeding methods, they can fall out.

However, when your teeth are arranged in rows, it's not a problem. When a gap appears in the shark's front row of teeth, the one from the row behind moves forward and fills the space. This could have allowed sharks to evolve the strong jaws and bites they're known for today, not worrying about the teeth they shed in doing so.

Young sharks replace teeth faster than older ones, and those that live in colder water may hold on to individual teeth longer, but a long-lived shark may go through as many as 30,000 teeth in its lifetime.

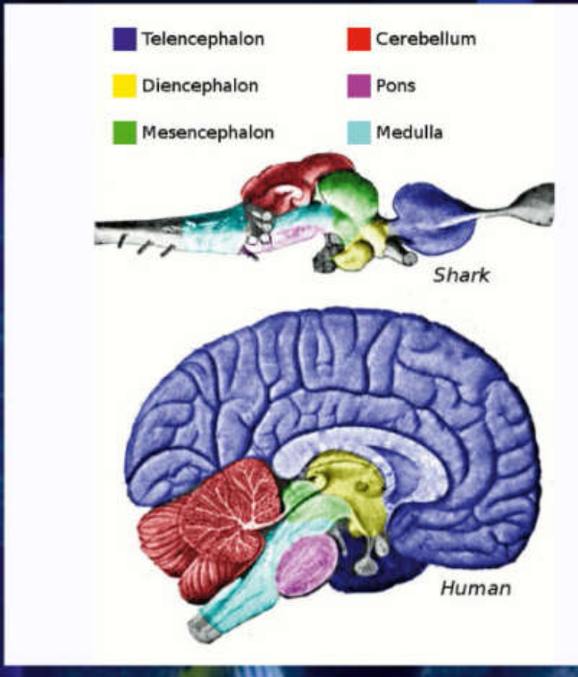
RIGHT A shark may work its way through an incredible 30,000 teeth in its lifetime

2. SHARK BRAINS ARE TINY

This myth comes from the perception of sharks as mindless killing machines, unable to think about anything except where their next meal will be found. And while it's true that sharks aren't big users of tools, written languages or YouTube, to call them walnut-brained is to do them a disservice.

For a start, the human brain is more like a walnut – round and wrinkled – than a shark's. Saw open the skull of a great white, for example, and you'll find nearly two feet of Y-shaped tissue arranged into distinct fore-, mid- and hind-brain sections, with two olfactory bulbs at the front that give the great white its fearsome sense of smell.

That said, a shark's brain is still small compared to its body. A human manages a brain to bodyweight ratio of 1:40, while a great white, thanks to its huge body, has a ratio of 1:2,496.



The chimera (relative to shark) has an eye for sex

Its sexual organ is between its eyes. Males have a tentaculum for clinging onto females

ABOVE According to research, sharks, like humans, aren't immune to cancer

3. SHARKS DON'T GET CANCER

We had to read that twice to get our bewildered brains around it, but it seems some in the alternative medicine community sell shark cartilage as a cure for cancer. Sharks are amazing creatures, but they're not that good. Aside from the fact that cancer isn't yet one disease that can be cured, the thinking behind the use of the cartilage is that sharks don't get cancer themselves.

Except they do. A 2004 study by the University of Hawaii found 42 tumours in cartilaginous fish, including sharks, just among the specimens in its own collection. There were even tumours in the cartilage itself.

What cartilage *can* do under certain circumstances is inhibit the growth of blood vessels towards a tumour if placed next to it, but this isn't an ability unique to shark cartilage and is a long way from ingesting magic shark pills to cure cancer.

4. SHARKS WILL EAT ANYTHING

Actually, this one might be true. Things found in shark stomachs include a full suit of knight's armour inside a great white (recorded by a 16th century Frenchman); car number plates and tyres; a cannonball; an unopened bottle of wine; and an entire reindeer, complete with antlers.

Sharks don't chew their food much, preferring instead to swallow prey whole or in chunks. The oesophagus of a great white is lined with finger-like protrusions that prevent food from climbing back out again before it reaches the stomach, which is U-shaped, able to expand, and comprises strong acids and enzymes that strip the fleshy parts before anything indigestible is vomited back up.

A shark's intestines are arranged in a spiral, and although short, have a large surface area for absorbing nutrients.

So while sharks may well bite anything, and swallow anything, they certainly can't digest anything.

Overfishing will not only lead to shark extinction, but have a devastating effect on the entire ecosystem, too

5. THEIR EXTINCTION WOULDN'T MATTER

Writing down all the mysteries surrounding sharks could fill a publication twice this size. Scientists have no idea where many species of shark breed, where they migrate to, or even what they eat. New species are discovered every year, as humans push further into the deep oceans and isolated island ecosystems that are their homes.

As the secret places sharks migrate to become known, so the sharks are pushed closer to the edge of extinction. The top predator in an ecosystem has a specific role. It keeps the populations of prey species healthy by picking off the weak and the injured, but when humans remove a predator species, the whole food chain below them can collapse.

Overfishing in the Atlantic has led to a boom in jellyfish, which use up the nutrients that would otherwise be eaten by smaller creatures that fish feed on, leading to even fewer fish. Messing with these delicate systems rarely ends well.

Ian Evenden
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SCIENCE SHOT

+ Stunning images from the Earth's oceans

THE SHARK DESIGNED TO DETECT DINNER

Its head shape may look unusual, but it serves to locate the hammerhead's next meal

PHOTO © THINKSTOCK

The hammerhead shark's head shape seems to have evolved for two main reasons. The first is to give it a wide field of vision – the shark can see above and below itself, as well as partially behind. A second benefit is that it widens the area covered by its ampullae of Lorenzini, enabling the hammerhead to sweep the seabed like a metal detector, picking up the electrical impulses of rays and other prey buried in the sand. Unlike other sharks, hammerheads are found in large schools during the day, reverting to a solitary hunter role by night. DS

Occasionally whale sharks gather to feed

In 2009, over 400 of them assembled in the sea off Mexico

UNLIKE OTHER SHARKS, HAMMERHEADS ARE FOUND IN SCHOOLS IN THE DAY, REVERTING TO A SOLITARY HUNTER ROLE BY NIGHT

The great white is grey above and white below

This two-tone colour scheme is hard to see from either angle

PRIVATE LIFE OF A MOVIE STAR

They're portrayed as a ruthless killer but the great white shark has a softer side

WORDS BY **Ian Evenden**

Forty years ago, Steven Spielberg made *Jaws*, the film that made us fear the great white shark. Since then, from *Deep Blue Sea* to *Sharknado 3*, its presentation in the media has consistently been as a merciless predator, interested only in what it can kill and eat.

Reality, as is often the case, is somewhat different. The great white shark is a creature whose life continues to be studied, and those carrying out the research concede that there are gaps in their knowledge about the shark's behaviour.

Some aspects illustrated by Hollywood are certainly true – the great white shark is a sublime killing machine, the world's largest predatory fish and found in all oceans apart from those around the poles.

It's not a common fish; indeed it has been classified as 'vulnerable' by the International Union for Conservation of Nature. Why is down to three key reasons: it reaches maturity slowly, is a favourite among sport fishermen and no accurate figure has ever been put on its population. Generally solitary creatures, great whites will congregate around a source of food. While young sharks may feed on fish, adults are particularly fond of marine mammals, such as seals and sealions, though they're not that picky about what they feast on.

LONESOME AT THE TOP

We spoke to Tobey Curtis, a scientist at the National Oceanic and

Female great whites are bigger than males

That's bad luck for the men as larger sharks dominate smaller ones at feeding sites

Tiger sharks will eat anything

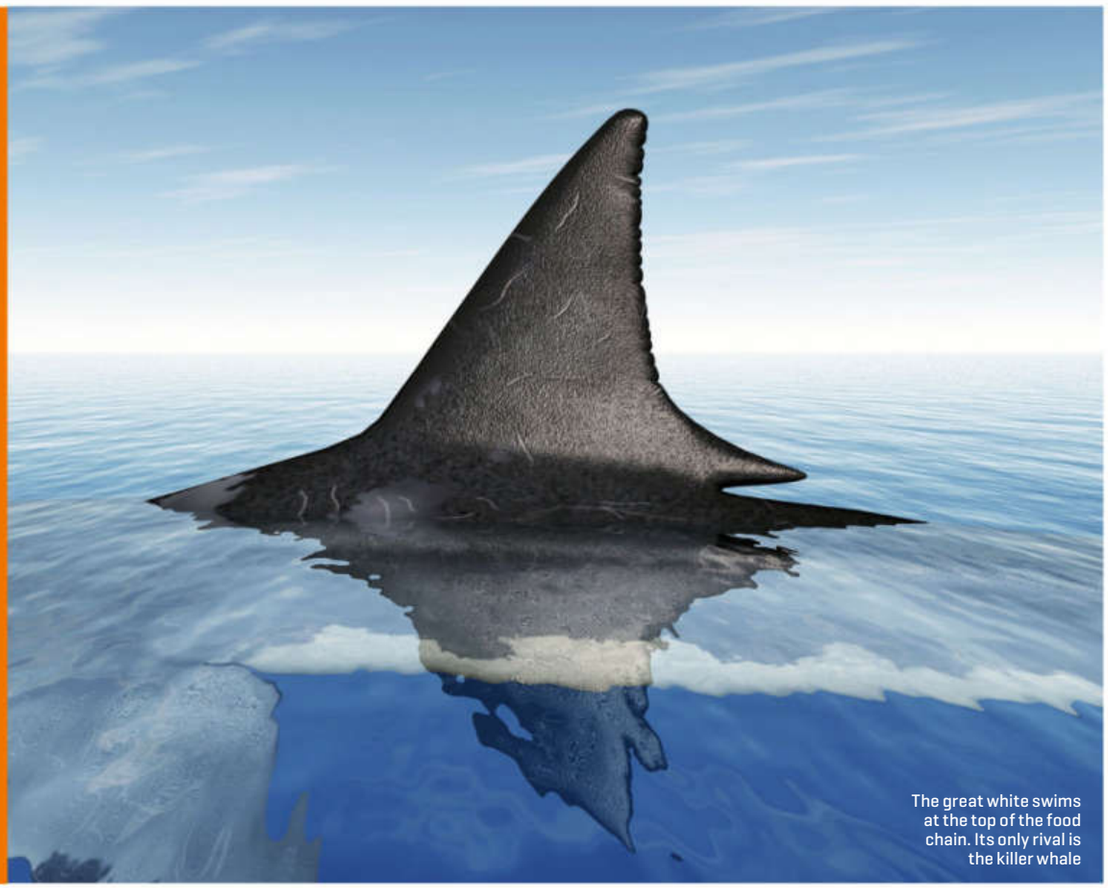
They'll even carry off and chew a cameraman's photography equipment

SHARK NAVIGATION

The great white doubles as a natural Tom Tom... but how?

+ Great whites can travel huge distances between feeding hotspots, but no one's quite sure how. As they're able to find their way in darkness, it's thought they're not using vision as their only means of navigation. Instead, theories include painting and retaining a mental map of the ocean floor, or sensing the Earth's magnetic field as they swim.

In 2005, a shark was recorded swimming more than 11,000 miles from South Africa to Western Australia and back in just nine months, and while it's possible it set out in a randomly chosen direction, the return leg suggests planning and knowledge of where it was going.



The great white swims at the top of the food chain. Its only rival is the killer whale

Though feeding hotspots like dead whales attract schools, sharks are solitary travellers

GREAT WHITES HAVE BEEN SPOTTED OFF NEWFOUNDLAND ON THE SAME LATITUDE AS THE SOUTH OF ENGLAND

Atmospheric Administration in the US who specialises in the study of Atlantic sharks, and he told us more about what great whites get up to all day. "A dead whale floating by will generally draw in multiple sharks to a small area," he explains. "There are feeding hotspots where the sharks will aggregate, and interact with one another, but as far as we know their travels are more solitary. They don't travel in schools like a lot of fish."

This lonesome lifestyle's not a danger when you're top of the food chain. Apart from humans, there's only one animal that can hunt a great white shark. "It's an orca," says Curtis. "An adult orca can be twice as long as a big white shark, much larger and more powerful. It usually only takes a single orca to deal with a white shark. They grab them, and turn them over underwater, and can take massive bites out of them."

DEATH BY DROWNING

It's the turning over that may be key to the killer whale's success at shark hunting. Many fish, great whites among them, fall into a limp state known as tonic immobility that prevents them from fighting back against the orca – or indeed doing anything else. "It's a sensory overload situation," says Curtis. "It's so unnatural and disorienting for a shark to be inverted." In 1997 a female orca in the seas off San Francisco was documented holding a great white upside down for up to 15 minutes, drowning it.

How do you drown a fish? All sharks rely on the flow of water over their gills to absorb oxygen, but some species can use their mouths like a pump to keep the water coming, allowing them to sit motionless on the seabed waiting for prey. Great whites can't do this, and must forever swim forwards – if they stop, or are stopped, they will die from lack of oxygen.

This throws up another question: if it can't stop, how does it sleep? This is an area in which research has yet to provide many answers. One hypothesis is that the shark can shut down its hind-, mid- and fore-brain independently, leading

Many sharks have an unusual stomach trick

They can squeeze them out of their mouths. This dumps anything undigested

The isla de Guadaloupe, 150 miles from Mexico, is a dramatic setting to observe great whites

PLACES TO SEE GREAT WHITES

Four hotspots to spot the most enigmatic creature in the ocean

SEAL ISLAND, SOUTH AFRICA

South African boats love to tow lures to encourage sharks to breach, flinging themselves from the water, but they do it naturally too when they hunt. A ton of shark leaping three metres makes for a spectacular photograph. You'll observe the most sharks between April and September.

ISLA DE GUADALOUPE, MEXICO

This volcanic island, 150 miles off the coast of Mexico, features clear waters and local boats equipped with cages for safe shark viewing 10m below the surface as they hunt the local population of fur seals. Peak shark viewing time is August to October.

FARALLON ISLANDS, CALIFORNIA

Head 30 miles out of San Francisco into the Pacific and you'll find the US's largest seabird breeding colony. It's also home to elephant seals, and this in turn draws in great whites. The elephant seal is a large animal and a huge shark taking one is a dramatic sight. Go from September to November.

NEPTUNE ISLANDS, SOUTH AUSTRALIA

Home of the New Zealand fur seal, these islands 140 miles out of Adelaide bring in great whites in both summer and winter, but the biggest sharks are said to be there between November and February. This is where most of the real sharks in *Jaws* were filmed.

IMAGE © THINKSTOCK

to the underwater equivalent of sleepwalking, while research on the small shark known as the dogfish suggests the nerves that regulate its swimming action may lie in the spinal cord rather than the brain, allowing it to keep going, even while dozing.

20,000 MILES AND COUNTING

And keep going they do, with a shark in 2014 tracked for over 20,000 miles as she crossed the Atlantic Ocean and meandered up the east coast of the US. Great whites have been observed as far north as Newfoundland, on the same latitude as the south of England, and are regularly spotted off the southern tip of South Africa.

Their travels take them where the food is. "Some of these sharks swim to Hawaii and back over the course of a year," says Curtis. "There appears to be a sort of feeding hotspot out in the middle of the Pacific Ocean. It seems that they're diving deep so it may be deep-sea squid or fish that they're being attracted to.

"In the north Atlantic they move up and down the east coast of the US as the seasons progress, but they do also occasionally go well offshore, out to Bermuda and down to the Bahamas. A large white shark can really go wherever it wants."

Wherever it goes, the great white is able to keep its body temperature above that of the water around it. Its whole family, the Lamnidae, are able to do this, and are all fast, heavily built predatory fish such as the porbeagle and mako shark. "They have the ability to elevate the body temperature in certain parts of their bodies like the heart and parts of their brain," says Curtis. "They have a unique blood vessel physiology that traps heat in their body. It gives them a real predatory advantage because these sharks generally prefer temperate, cooler waters, so that elevated

GREAT WHITES AND HUMANS

+ The great white is responsible for the largest number of confirmed attacks on humans, though it's not thought they are hunting us for food, but are instead attracted by our rhythmic movements. Many attacks may be 'test bites', in which the shark uses its mouth to discover what this strange creature is, before spitting the human out because it's an unfamiliar taste that contains too much bone for the shark's digestion.

For the swimmer, that first bite may well prove fatal. With up to 300 triangular teeth that are constantly being replaced, a bite from a great white is no laughing matter. If attacked by a shark, the advice is to punch at its sensitive snout, eyes and gill slits to make it retreat - but the great white is the master of its element and avoiding such confrontations is the best way to stay safe.

IMAGE © FAE/WIKIMEDIA

RANDOM MATTER

Great whites may follow the stars

It explains both their straight-line journeys and habit of putting their heads above water

SHARK SENSES

Who needs sonar when you have Mother Nature

+ They might not feature lobed ears, two legs and excessive nasal hair, but sharks possess all the senses – and more – that humans have. All of these senses combine to ensure a shark survives in a diverse range of habitats, can navigate the oceans, efficiently hunts prey and can even detect the pheromones of a potential mate. Read on to find out more...

SMELL AND TASTE

+ The great white's keenest sense is that of smell. Its olfactory bulb is the largest of any shark – up to two thirds of the volume of its brain – leading to a very sensitive snout. The great white can detect one drop of blood in 10 billion drops of water, enabling it to home in on prey that has been injured and is easier to catch.

EYESIGHT

+ It's a myth that sharks have poor vision. The great white's eyes contain the identical rods and cones as our own, allowing it to see colour even if we have no way of knowing how it interprets this. The great white doesn't have eyelids or even a nictitating membrane to protect its eyes, but instead rolls its eyeball back into the socket when attacking prey.

TOUCH

+ Like all fish, the great white has a lateral line running the length of its body, which senses movement and vibration transmitted through the water. The line is filled with a jelly-like substance, into which are embedded tiny hairs that tie into nerves beneath the skin. As pressure waves arrive in the jelly, the hairs flex and transmit this information to the nerves.

HEARING

+ The great white doesn't have prominent ears, but sound travels well underwater. While two small holes behind the eyes are all we see on the outside of the great white, it can detect movement from over 200m away through sound. Inside the shark's inner ear are fluid-filled canals similar to those in human ears, which allow it to keep its balance and maintain its position in three dimensions.

ELECTRO

+ Every living thing crates an electric field around itself, and sharks can feel it using their ampullae of Lorenzini - jelly-filled pores in the skin clustered around the head. Sensitive down to five billionths of a volt, and also thought capable of measuring temperature, the ampullae are a literal sixth sense for perceiving the world and finding prey.

THE GREAT WHITE CAN DETECT ONE DROP OF BLOOD IN 10 BILLION DROPS OF WATER, ENABLING IT TO HOME IN ON INJURED PREY

RIGHT The great white has been known to leap up to 10 feet out of the water

metabolism and the ability to stay warm improves their muscle activity so they can swim faster. White sharks can keep their stomach more than 10°c above water temperature."

The great white's also more emotionally aware than many would suspect. Cameramen who get in the water with the creatures report an arching of the back and a display of the black tips of the pectoral fins as a warning to back off or face the consequences, and the great white's habit of sticking its head out of the water to examine objects on the surface points to an animal with a curious side. "I've seen a lot of them in the water and it's almost as if they don't realise their size advantage," says Curtis. "Sometimes they come to the surface and they're not sure what you are, so they'll look under the boat and they'll circle or sometimes roll on their side, and you can see them looking at you. Sharks are more intelligent than they are given credit for – white sharks, in particular."

ABOVE Great whites are portrayed as thoughtless killers, but they're much more intelligent than that

ELEVATED METABOLISM AND THE ABILITY TO STAY WARM HELPS THE GREAT WHITE TO SWIM FASTER

An intelligent creature with a bad reputation, the great white shark will continue to impress us with its speed, power and mouth full of serrated teeth. You just might not want to attract too much of its curiosity while swimming.

HOW DO YOU TAG A SHARK?

Folllowing a shark requires composure and a very long pole

+ Sharks' movements are tracked by embedding a tag into their skin that communicates with a satellite orbiting above the Earth. However, getting the tag into six metres of apex predator would seem easier said than done. Shark skin is rough to touch. Instead of scales like fish skin, it comprises thousands of tiny tooth-like structures called 'dermal denticles', which streamline the shark for faster movement through the water.

Getting a tag through this skin is difficult but not impossible, according to the National Oceanic and Atmospheric Administration's Tobey Curtis. "When you're out in a small boat with a great white shark, they might just ignore you completely as they're out there looking for seals," he says. "A lot of times a field target, like an old wetsuit that's shaped like a seal, is used. The sharks will come up and try to bite it, and as they swim by you'll have your tag on the end of a pole and you just poke it into their back."

Mind you, first you've got to find your shark. "Off Cape Cod we've been using spotter pilots," says Curtis. "In shallow, sandy waters, great whites stick out like a sore thumb when you fly over them, and they guide our tagging boat right up over the sharks. White sharks are actually easier to tag than a lot of species, as others need to be caught with a hook and line. With white sharks you just need to sneak up on them."

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RANDOM MATTER

Cookiecutter sharks bite neat chunks

As a result, underwater cables are now coated and wrapped in fibreglass armour

LIGHTS, CAMERA… ACTION

IMAGE © MIGRATION MEDIA

Filming the ultimate predator requires a cage constructed from stainless steel? Maybe not…

WORDS BY **Ian Evenden**

Getting into the water with sharks may seem foolhardy, but if you want spectacular footage of these top predators in their natural environment, it's the only way.

Filmmaker Ed Cardwell films sharks without the protection of a cage in the seas off Western Australia's Ningaloo Reef for his company Migration Media, which he co-owns with his partner Hayley. Species in the area include reef sharks, bronze whalers and tiger sharks, with great whites further out to sea.

"With anything in the water you're getting as close as you can, as the visibility underwater is always less than it is above water. You have to get close otherwise you're not going to see clearly," he says.

"I wear normal diving gear; I've never used a cage. You tend to find that larger female sharks are more comfortable in the water with humans. It's a bit like with people: juvenile males are trying to prove themselves whereas the bigger females are beautiful. They just swan around feeling comfortable."

Still, that's a big apex predator, so doesn't he feel in danger? "I've never got out of the water because I wasn't comfortable," Cardwell says. "That said, there are definitely times where you feel you need to act a certain way so that you're not seen as prey. Bigger sharks are particularly inquisitive. They'll charge at you and turn sideways to show you just how enormous they are. The more they do it, the closer they get each time, and it reaches a point where you need to show your dominance in the water."

And if showing dominance to a shark sounds crazy, the way it's done is to make yourself as big as possible. "Firstly, you can't transmit your nerves," explains Cardwell. "There are times when you need to start approaching them and do a similar thing to what they might do. I had an accident with my boat once and had to swim back to shore. It was about five miles and I was starting to feel like prey as I had a couple of bull sharks that were circling below me."

It's worth noting at this point that Cardwell is alive enough to tell us this story. He continues: "Sharks pick up on electrical impulses, and one thing that generates these is cramp, so if your legs start cramping up, sharks can pick up on that. My legs were cramping and I had to dive down and charge the sharks to scare them off. That was probably the most threatened I've felt in the water. Mind you, when you're holding a big camera in front of you, it feels like a protective barrier. You can butt them away with the front of the housing, which is often quite helpful."

ABOVE Though rare, sizeable underwater cameras can double as a cameraman's shield

Ian Evenden
Science writer

+ Ian Evenden is an experienced and highly acclaimed freelance journalist working in the fields of science, technology and digital photography. *@ievenden*

RANDOM MATTER

Tiger shark teeth are like saws

This means that they can easily cut through the shells of turtles

FINISHED?

Unless suitable steps are taken, the future for our oceans' top predators is bleak

WORDS BY **Ian Evenden**

There's a species on this planet that loves to eat sharks, pulling them from the sea and consuming them in ever-increasing numbers. That species is, of course, the human. Some humans, however, are campaigning to save the sharks in our oceans before they're gone for good.

"Sharks and their relatives are one of the most threatened groups of vertebrates on the planet," says Ali Hood, director of conservation at the Shark Trust, the UK's only shark conservation charity. "Sharks are at a tipping point in many ways, with a number of species genuinely on the brink. Despite an increase in management, numerous species still face substantial danger, with recent reports identifying over a quarter of all sharks and rays as threatened."

It's the meat and fins of the sharks that makes them such a popular target for commercial fishermen, but they also get caught up in the nets of fishing fleets looking for other types of fish – so called bycatch that's thrown back into the sea, but often not soon enough to save the sharks, who asphyxiate on the deck of the trawler.

"There are a number of shark species that are in serious trouble," says Hood. "Large, flat-bodied species found in coastal waters are most vulnerable to overexploitation and fishery pressure simply because you can catch them more easily. We've seen a number of species, such as the angel shark, reach endangered levels. They are regionally extinct through large tracts of our coastline."

Fast-moving sharks are in trouble, too. Hood continues: "There's a market for the high-end species, such as shortfin mako and porbeagle, whose meat is highly valued alongside swordfish and tuna. You also have other species of shark that represent a cheap source of protein, and that is in high demand in other markets. For instance, there's a growing market in Brazil, and there's also a very strong market here in Europe, particularly in Italy where shark is consumed in substantial quantities."

Spain is the second largest shark fishing nation, but Europe may be changing the way it looks at sharks. "We have a strong opportunity for Europe to act for shark conservation and management," says Hood. "In 2013, Europe revised their shark-finning regulations to require all sharks to be landed with their fins 'naturally attached' rather than the previous complicated and loophole-ridden ratio system. Europe is championing fins-attached landings but, unfortunately, high-seas management bodies work by consensus, and this best practice is being blocked by countries that would rather not see it happen."

Humans are the shark's worst enemy, but there are many out there acting to ensure that they don't become extinct. For the sharks' sake, we have to hope they prevail.

DESPITE AN INCREASE IN MANAGEMENT, A NUMBER OF SPECIES STILL FACE SUBSTANTIAL DANGER WITH OVER A QUARTER OF SHARKS THREATENED

LIVER OIL

Known as squalene and found in cosmetics, it's produced in our skins and is a moisturiser, but sharks use it to regulate buoyancy as it's less dense than water. Thankfully, shark-obtained oil is on the decline due to vegetable alternatives.

MEAT

The popularity of shark meat is rising and it's beginning to be sold in supermarkets, often under names such as rock salmon or sea eel. It's also found in composite fish products, such as crab sticks or fish cakes. It also makes up a proportion of animal food and fertilisers.

CARTILAGE

Powdered shark cartilage is sold as a supplement with supposed abilities to treat joint and skin conditions. There is little or no clinical evidence that these pills and powders work.

SKIN

Sharkskin has been used to make leather for centuries because it's extremely durable. Untanned skin is used in furniture making as a type of sandpaper, called Shagreen, or as a book binding.

TEETH

Shark teeth are a common sight among souvenir shops in shark fishing areas, sold individually or formed into jewellery. A whole set of jaws from a great white (a protected species under the CITES treaty) can be bought for around £5,000.

ABOVE "Shark populations must be managed now before the population crashes," says Ali Hood

NO LIMITS

The Shark Trust is lobbying to stop uncontrolled shark fishing with its 'No Limits? No Future' campaign.

+ "It's important that the public engage in shark conservation work," says Ali Hood, director of conservation at the Shark Trust. "With 'No Limits? No Future', we want to stop uncontrolled shark fishing now."

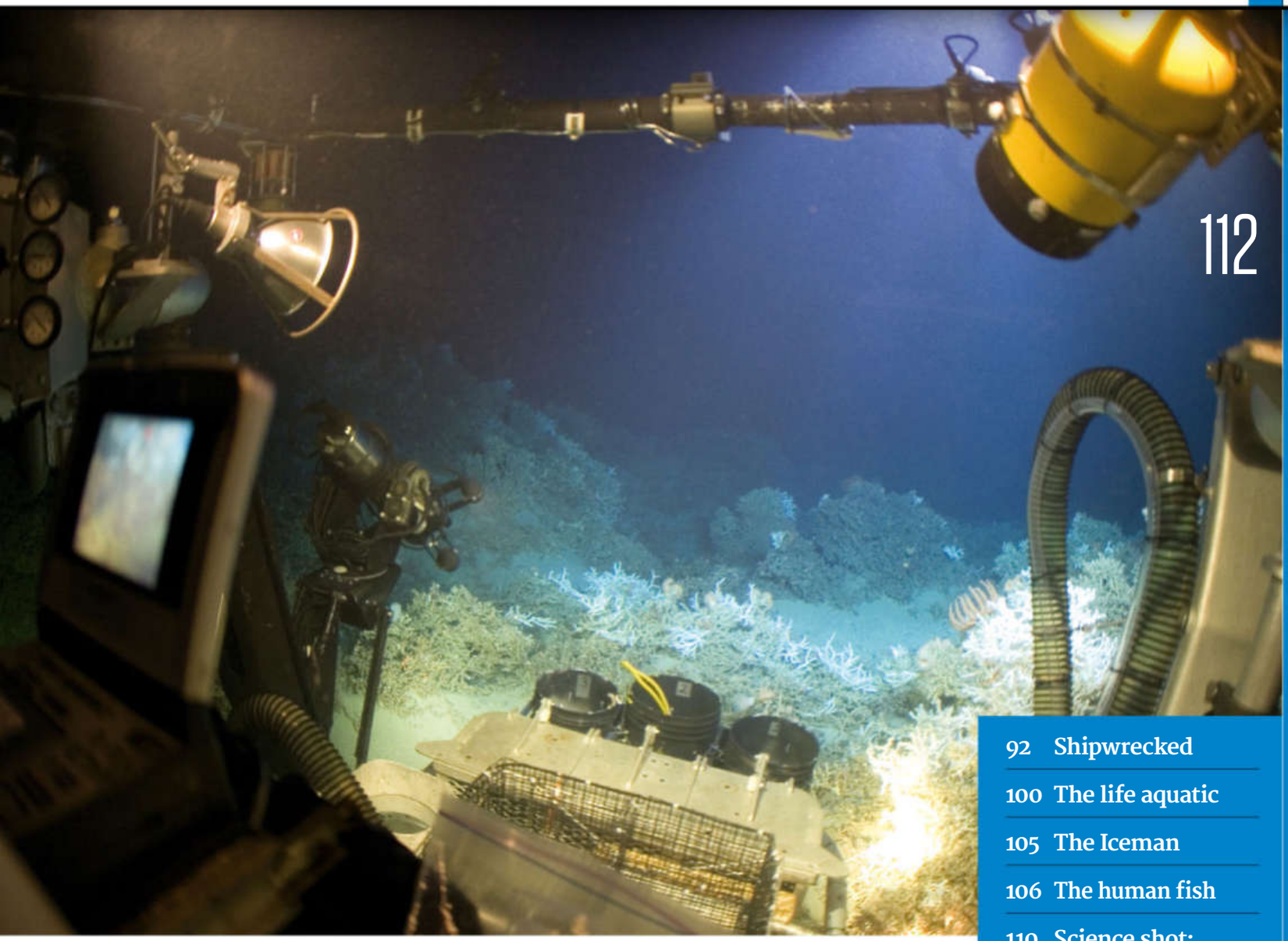
In 2012, over 280,000 tons of sharks were landed. The actual weight of sharks killed is likely to greatly exceed this figure as it doesn't take into account bycatch. "That's why we're working for science-based limits on shark fishing," says Hood, "and for clear scientific advice to be given to management bodies such as the European Commission or regional fishing management organisations."

The campaign is focused on blue sharks, shortfin mako and, in coastal waters, the smoothhound, catshark and tope. Some smaller coastal species have come under additional pressure in recent years due to management of other species of shark or the need for fishermen to diversify from traditional target species when their populations have declined.

"It's important to note that while some populations of sharks may be found in relatively large numbers, in the absence of management they may still be declining – as with the blue shark," says Hill.

The blue shark has seen a threefold increase in landings from the Atlantic by the European fleet in the last 10 years. Globally, 2003 saw a peak of landings and a subsequent decline, but the pattern of blue shark landings in Europe is bucking that trend. Hill continues: "To ensure a sustainable future we need to understand the status of populations so as to manage these populations effectively. It's very logical. Manage the populations now before that population crashes."

EXPLORATION



"PUGH SWAM IN -1°C WATERS AGAINST AN AIR TEMPERATURE OF A CHILLING -37°C"

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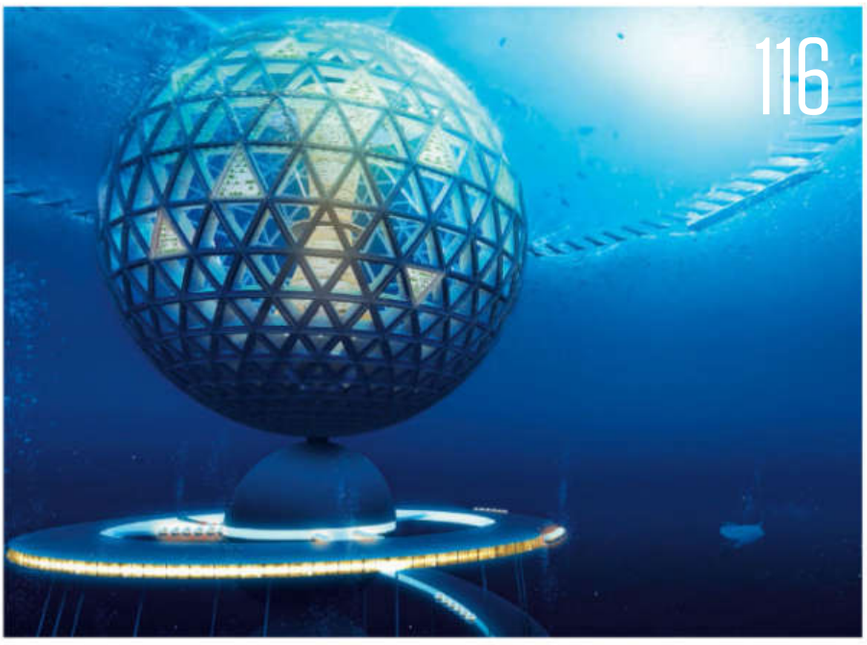
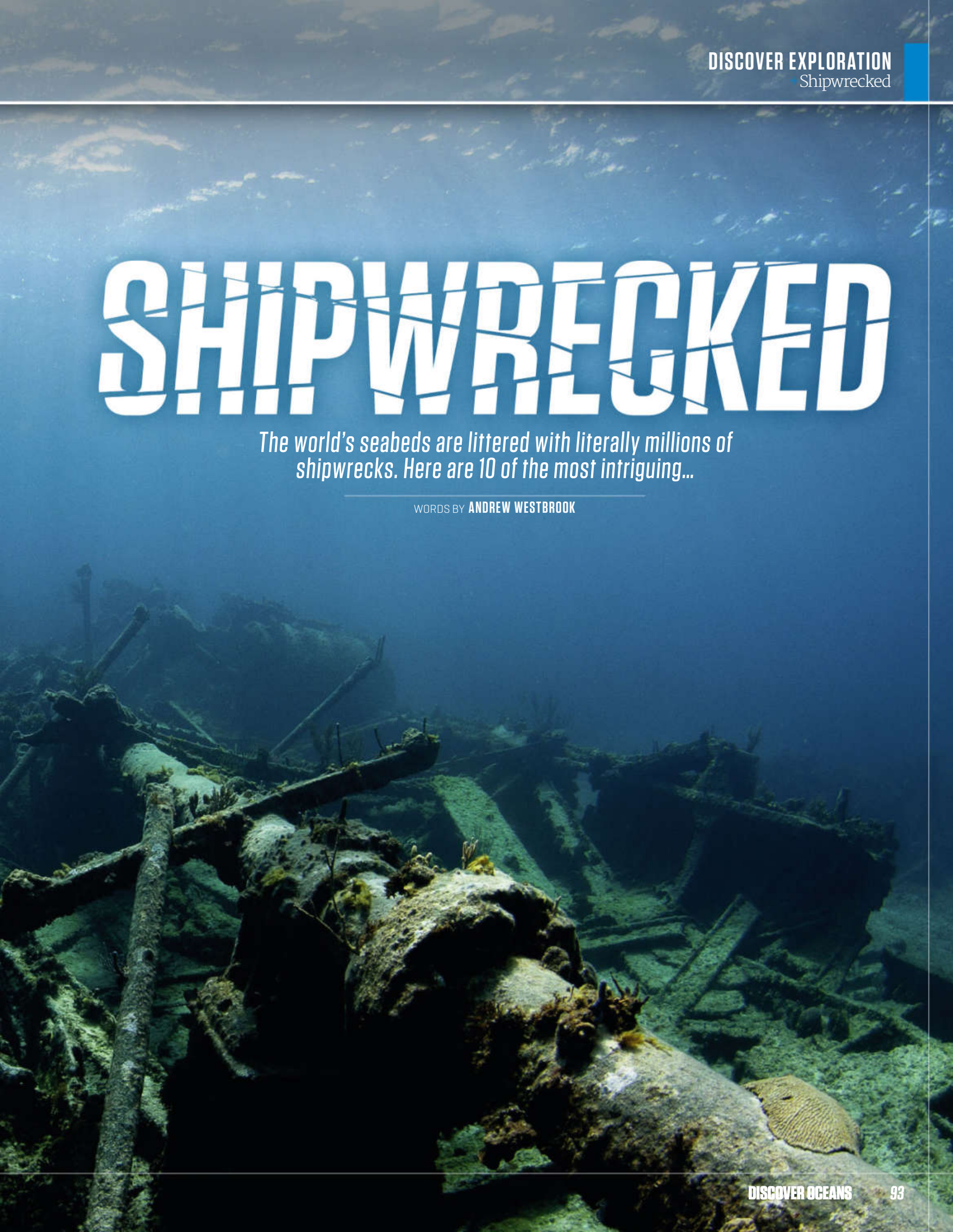


SHIPWRECKED

The world's seabeds are littered with literally millions of shipwrecks. Here are 10 of the most intriguing...

WORDS BY **ANDREW WESTBROOK**



RANDOM MATTER

The Titanic had four more lifeboats than legally required

It carried 20, though that was still only enough for half the passengers

10 THE SS YONGALA

The shipwreck the wildlife loves

Perched at the bottom of a shallow shipping lane by Australia's Great Barrier Reef for just over a century, the Yongala has become a major hub for marine life. Barracudas, giant groupers, rays, turtles, sharks, sea snakes and a host of other marine species are all regularly sighted at the now coral-dusted wreck, which has also become a hub for human life thanks to its status as one of the world's best dive sites.

Times were not always so glamorous for the Yongala. Built in England for the Adelaide Steamship Company, and given an Aboriginal word meaning 'good water' as a name, the Yongala entered service in 1903. The steel and timber steamship worked several routes around Australia, transporting passengers and freight, before it sank during a tropical cyclone, in 1911, still about 90km from its destination of Townsville in Queensland. Believing the ship was merely taking shelter from the storm, as was common practice, the authorities waited several days before raising the alarm. By then, it was way too late. All 122 people on board were lost. Parts of the wreckage started washing up on shore, but a major search failed to find the Yongala. Despite being 109m long and only about 30m under the water, plus being identified as a possible wreck by survey ship HMAS Lachlan in 1947, the Yongala wasn't officially discovered until 1958, when local fisherman Bill Kirkpatrick began searching the area in detail.

The ship was formally identified by a serial number found inside a steel safe.

THE STEEL AND TIMBER STEAMSHIP WORKED SEVERAL ROUTES AROUND AUSTRALIA BEFORE IT SANK DURING A TROPICAL CYCLONE IN 1911

A flattened 360° image of a school of rays soaring across one of the Yongala's more eroded sections

IMAGE @ CATLIN SEAVIEW SURVEY

IMAGE @ GROPLAN PROJECT. CNRS LSIS/ CNRS CCJ / UNIVERSITY OF MALTA

ABOVE The French-funded Groplan project's Remora 2000 submarine takes a detailed examination of the 2,700-year-old pots off Malta

THE EXPEDITION TEAM IS USING MORE THAN 8,000 PHOTOS OF THE SITE TO CONSTRUCT A HIGH-RESOLUTION 3D MODEL

9 ANCIENT PHOENICIAN VESSEL

Is this the oldest shipwreck that nestles on the seabed of the Mediterranean?

Remote sensing surveys last year chanced across what is thought to be a Phoenician merchant boat dating back to around 700BC. Found in waters about 125m deep, roughly 3km off the Maltese island of Gozo, the exact location of the 15m-long vessel is being kept secret until further studies are carried out.

Early indications of the boat's vintage are promising, with experts dating its contents back around 2,700 years. Underwater archaeologists from the French-funded Groplan project have found 20 grinding stones, weighing 35kg each, and 50 wine-holding amphorae, of seven different types, suggesting the vessel was widely travelled. It's thought it was crossing from Sicily to Malta when it sank.

The expedition team is using more than 8,000 photos of the site to construct a high-resolution 3D model, while also attempting to bring more pieces of the wreck to the surface.

The find is considered particularly vital because so little is known about the Phoenicians, who lived near present-day Lebanon and were major seafaring traders, as well as leaders in ship-building, between 1,500BC and 300BC.

8 SS THISTLEGORM

The underwater transport museum in the Red Sea

Trucks, motorbikes, jeeps, tanks and even trains – just about every mode of transport can be found within the sunken cargo holds of British freighter the SS Thistlegorm. Built in Sunderland, in 1940, the Thistlegorm was an armed transporter, complete with anti-aircraft gun, for the Merchant Navy during World War II. After criss-crossing the war-torn world on voyages to the US, Argentina and the West Indies, the Thistlegorm was dispatched to Alexandria in Egypt. Tasked with delivering supplies to the Allies' Eighth Army, the Thistlegorm was packed with ammunition, Bren guns and aeroplane parts, plus fleets of Bedford trucks, armoured vehicles, Norton 16H and BSA motorbikes, as well as at least two steam locomotives. Needing to avoid the Axis-dominated Mediterranean, the Thistlegorm travelled in convoy via Cape Town. Coming up the Red Sea, the ships took shelter in the Strait of Gubal, near Hurghada, while waiting for a blockage to be cleared in the Suez Canal. The anchored freighters, however, caught the eye of passing German bombers. Targeting the Thistlegorm – the convoy's largest ship – the Luftwaffe connected with two bombs. Setting off the on-board stores of ammunition, the bombs caused an almighty explosion, blasting the locomotives into the surrounding waters and rapidly sinking the Thistlegorm, with the rest of its cargo still secured. Miraculously, only nine of the 41-man crew were killed. Lying around 30m deep, the wreck was made famous by a 1955 Jacques Cousteau visit, and since the 1990s has become the top wreck-diving destination in the Red Sea.

BUILT IN SUNDERLAND IN 1940, THE THISTLEGORM WAS AN ARMED TRANSPORTER FOR THE NAVY DURING WORLD WAR II

One of the LMS Stanier Class 8F steam locomotives blown off the Thistlegorm's deck when it was bombed

IMAGE © ADAM MORIARTY/WWW.FLICKR.COM/PHOTOS/GHOST

7 SS CENTRAL AMERICA

The ship that almost sank the economy

A contemporary lithograph depicting the sinking of the SS Central America

IMAGES @ J. CHILDS, PHILADELPHIA; ODYSSEY MARINE EXPLORATION, INC.

DESPITE TAKING TWO DAYS TO SINK, THE WEATHER WAS SO BAD THAT ONLY 206 PEOPLE COULD BE RESCUED

The wrecking of the SS Central America is unusual – it led not only to the deaths of 426 people, but also contributed to a US financial crisis. Known as the 'ship of gold', the side-wheeled steamship was a vital cog in the Californian gold rush. As much as a third of the gold discovered in that time is thought to have been carried on her decks, which hopped between New York and Panama, linking up with a San Francisco connection. By 1857, however, the rush had slowed, and the New York banks, overstretched by risky investments, began to struggle.

The banks, desperate for cash supplies, called on the Central America. And so it left Panama, carrying 20 tons of gold. But a hurricane, 300km off South Carolina, meant it never arrived. Despite taking two days to sink, the weather was so bad that only 206 people could be rescued. And the banks didn't get their gold, helping fuel the 'Panic of 1857'.

The ship was discovered by treasure hunter Tommy Thompson in 1988, who recovered gold worth an estimated $50 million. He was swiftly challenged by 39 insurance companies, which claimed to have paid out for the gold when it sunk, but the court sided with Thompson, awarding his team 92% of the findings. Investors, allegedly unpaid, were after Thompson next, until in 2012 he went on the run. Finally found in 2015, he's currently awaiting a court date. Salvage company Odyssey, meanwhile, is now at the Central America, and has started recovering more gold.

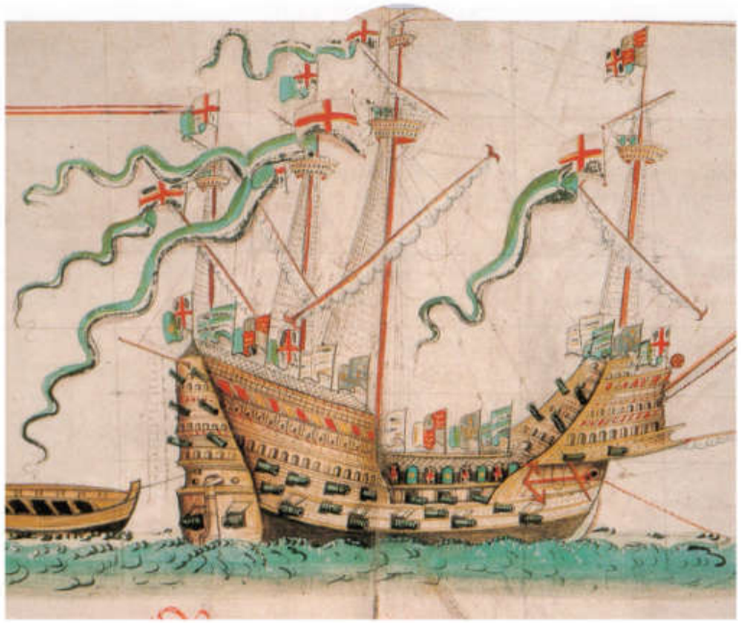
RANDOM MATTER

The Mary Rose crew had an average height of 5ft 7in

Researchers reached that conclusion after DNA testing human remains found within the wreck

6 THE MARY ROSE

Henry VIII's warship is a reminder of England's battles with the French



ANTHONY ROLL/WIKI CREATIVE COMMONS; VICTOR HABBICK VISIONS/SCIENCE PHOTO LIBRARY

ABOVE The Mary Rose, as depicted in the Anthony Roll – a 1545 record of Henry VIII's navy

This Tudor powerhouse fought in three wars in 34 years, before sinking off Portsmouth during a battle with the French. Since rising from her watery grave, she's now the only 16th-century warship on display anywhere in the world. Built at a time of naval expansion, the Mary Rose played a significant role in Henry VIII's newly created and permanent Royal Navy.

After first seeing action against the French in 1512, her end came in 1545 at the Battle of the Solent. Mystery, however, surrounds why the Mary capsized, sinking so quickly

THE MARY ROSE PLAYED A SIGNIFICANT ROLE IN HENRY VIII'S NEWLY-CREATED ROYAL NAVY

that all but 25 of the 400 men on board died. A combination of human error, windy weather and being overloaded is thought to be the most likely explanation.

The wreck was rediscovered by Alexander McKee in 1971. Then, in 1982, after years of work by a 500-strong team of volunteers, the ship's starboard side with four deck levels was raised from the seabed in a £4 million operation.

More than 19,000 artefacts, including skeletons, weapons and games, have been recovered, while the lengthy conservation work on the waterlogged wood of the hull, on display at Portsmouth's Mary Rose Museum, is due to finish in 2016.

5 THE VASA

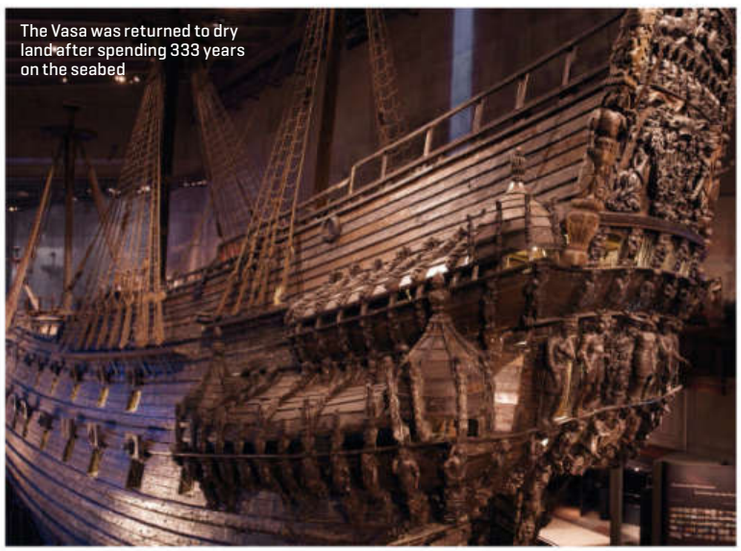
The world's largest archaeologically recovered ship didn't even last a mile

Like England's Mary Rose, 17th-century Swedish warship the Vasa also capsized and sank after its lower gunports flooded. And also like the Mary Rose, it was the subject of a massive archaeological project that saw it being raised again to live in a museum on dry land. The Vasa's time in service, however, could not have been more different. Built in 1626 and arguably the most powerful warship of her day, the Vasa was intended to play an active role in the expansionist dreams of Sweden's King Gustav II, who spent 18 years of his 21-year reign at war.

By 1628, the Vasa was ready to join the action. Despite the captain voicing concerns about the ship's unbalanced proportions, she set sail, cheered on by excited crowds. The glory, however, was short-lived. Coming out of port beneath the Sodermalm cliffs, the Vasa's sails caught the wind for the first time. At which point, having travelled a whole 1,300m, she promptly sank. About 30 of the 150 people on board died.

HAVING TRAVELLED A WHOLE 1,300M, SHE PROMPTLY SANK. ABOUT 30 OF THE 150 PEOPLE ON BOARD DIED

Like the Mary Rose, an immediate attempt to salvage the ship proved fruitless and she was to lie beneath the waves for centuries. The wreck was finally rediscovered, in 1956, by amateur archaeologist Anders Franzen. He worked with the Swedish Navy, Maritime Museum and the Neptune salvage company to ensure the Vasa broke the water's surface in 1961. She now sits in a dedicated Stockholm museum, attracting more than a million visitors a year.

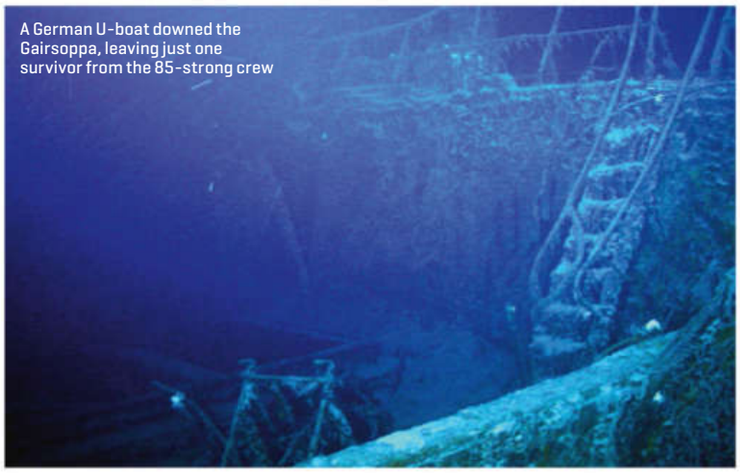


The Vasa was returned to dry land after spending 333 years on the seabed

IMAGE © OLA ERICSON/IMAGEBANK.SWEDEN.SE

4 SS GAIRSOPPA

The deepest and heaviest precious metal recovery in history



A German U-boat downed the Gairsoppa, leaving just one survivor from the 85-strong crew

IMAGE © ODYSSEY MARINE EXPLORATION, INC., WWW.ODYSSEYMARINE.COM

A tragic lesson in the dangers of going it alone during World War II, British steamship the Gairsoppa had been travelling from Calcutta to Liverpool, laden with around 7 million ounces of silver, when it was torpedoed by a German U-boat, sinking to a depth of 4,700m. Only one of the 85-strong crew survived.

The Gairsoppa had been making the 1941 trip as part of a merchant convoy. But delayed by poor weather and running low on fuel, the steamship was forced to split from the group and head for Galway on the western coast of neutral Ireland. Still almost 500km from shore, the U-boat struck. Despite also coming under machine gun fire from the Germans, 31 men, led by Second Officer Richard Ayres, managed to escape in a lifeboat. After 13 days, with just seven survivors left, land was spotted. It was the Cornish coast. The raft then capsized and four more men drowned. Washing up, battered on the rocks, two more died in the shallows, leaving just Ayres to be pulled to safety.

Fast forward to 2010 and the UK Government awarded American salvage company Odyssey Marine Exploration an exclusive contract to recover the cargo. To date, using advanced robotics, Odyssey has brought 110 tons of silver, or 2,792 ingots, to the surface. Under the deal, after Odyssey's expenses, the UK gets 20% of the booty, some of which was used in 2014 to produce 20,000 commemorative silver coins.

ABOVE The huge haul of silver has been salvaged from a depth of 4,700m, almost 1km deeper than the Titanic

TO DATE, USING ADVANCED ROBOTICS, ODYSSEY HAS BROUGHT 110 TONS OF SILVER, OR 2,792 INGOTS, TO THE SURFACE

3 THE FLOR DE LA MAR

The richest shipwreck never found continues to attract treasure hunters

Named the Flower of the Sea and with a cargo potentially worth billions, it's little surprise this sunken Portuguese carrack is top of the most wanted list for underwater treasure hunters. With reports suggesting the 16th-century vessel was carrying over 60 tons of intricate gold objects and 200 chests of gems, including diamonds the size of a man's fist, the Flor de la Mar is widely considered the most valuable vessel ever to sink.

Built in Lisbon in 1502, the Flor was tasked with transporting riches from the Indian colonies back to Portugal.

First captained by Estavao de Gama (cousin of Vasco), the Flor took part in two India runs before joining the fleet of Portuguese empire-builder Alfonso de Albuquerque, assisting in his 1510 conquest of Goa and 1511 conquest of Malacca. But heading back to Portugal with the vast spoils, the Flor was caught in a storm and wrecked, in the Straits of Malacca, off Sumatra. The Flor's location has remained a mystery ever since…

While some believe the ship was salvaged by locals in the 16th century, the search hasn't subsided. Indonesia's President Suharto spent $20 million looking, before hiring American treasure hunter Robert Marx. He claimed to find the wreck within three days, but the mission was halted when news got out. Multiple countries then lodged claims of ownership with the international court in The Hague, a case that still awaits a decision. It's little wonder, perhaps, that many doubt Marx's discovery, which might explain why salvage company drones continue to scour the Straits of Malacca.

The Malacca Maritime Museum, in Malaysia, is housed within a replica of the Flor de la Mar

IMAGE © TOURISM MALAYSIA

REPORTS SUGGEST THE 16TH-CENTURY VESSEL WAS CARRYING OVER 60 TONS OF INTRICATE GOLD OBJECTS

RANDOM MATTER

Odyssey had to return $500 million worth of treasure

The loss to Spain resulted from the company's search of the Nuestra Senora de las Mercedes

The San Francisco was sunk by a TBF Avenger torpedo bomber, the type of aircraft flown by future president George Bush during the war

IMAGE © ADAM MORIARTY/WWW.FLICKR.COM/PHOTOS/GHOST

2 THE SAN FRANCISCO MARU

The best-armed shipwreck among the remains of Japan's underwater World War II 'ghost fleet'

ABOVE One of the San Francisco's Type 95 Ha-Go tanks, about 50m deep, with its 37mm cannon rusty but still intact

It might be fair to call the San Francisco Maru, a Japanese freighter sat in Micronesia's Chuuk Lagoon, the world's most heavily armed shipwreck. It does, after all, boast a veritable armoury of bombs, trucks, torpedoes and mines, not to mention a trio of Type 95 light tanks, each weighing over seven tons. It would be more accurate, however, to call the *whole* of Chuuk Lagoon the world's most heavily armed seabed.

That's because this remote archipelago, 2,500km north-east of Australia, played a crucial role in World War II. Chuuk was home to the Combined Fleet of the Imperial Japanese Navy. As such, it was the target of 1944's Operation Hailstone, a massive US air and naval attack that left much of the base in ruins. Apparently catching the Japanese by surprise, with many of the ships still anchored, the level of destruction was staggering. The Japanese lost a submarine, dozens of ships, including four destroyers and 270 aircraft.

The remains of the 'ghost fleet' are still largely intact, and have become the promised land for divers since Jacques Cousteau filmed the area in 1969. Fighter aircraft, tanks, torpedoes and thousands of pieces of WW2 hardware are all visible, often in shallow water. It's the San Francisco, however, or 'million dollar wreck', that's seen as the pick of the fleet. Built in 1919 and brought out of retirement to carry military cargo, the 5,800-ton transporter was sunk by a 500lb bomb dropped by American aircraft. It now lies between 45m and 63m below the surface, packed to the gills with munitions and vehicles.

IN TWO DAYS THE JAPANESE LOST A SUBMARINE, DOZENS OF SHIPS AND 270 AIRCRAFT

1 THE TITANIC

The most famous boat in the world

THE WRECKAGE, IN TWO PIECES, WAS FOUND IN 1985 BY AMERICAN GEOLOGIST DR ROBERT BALLARD

Built in Belfast for the White Star Line shipping company, the Titanic is perhaps the most iconic ship of all time, however brief her service proved to be. When setting sail on her maiden voyage from Southampton to New York in 1912, the Titanic was the biggest, fastest and most extravagant cruise liner to have ever been built.

In an era of pre-war opulence and mass emigration to America, the more than 2,200 passengers and crew on board represented a huge cross-section of society.

Indeed, with a first-class suite costing up to £870, or about £72,000 in today's money, it's little surprise that aristocrats, politicians and even a silent movie star were on board. Financier JP Morgan, who'd helped bankroll the Titanic, was supposed to be travelling, but cancelled at the last minute.

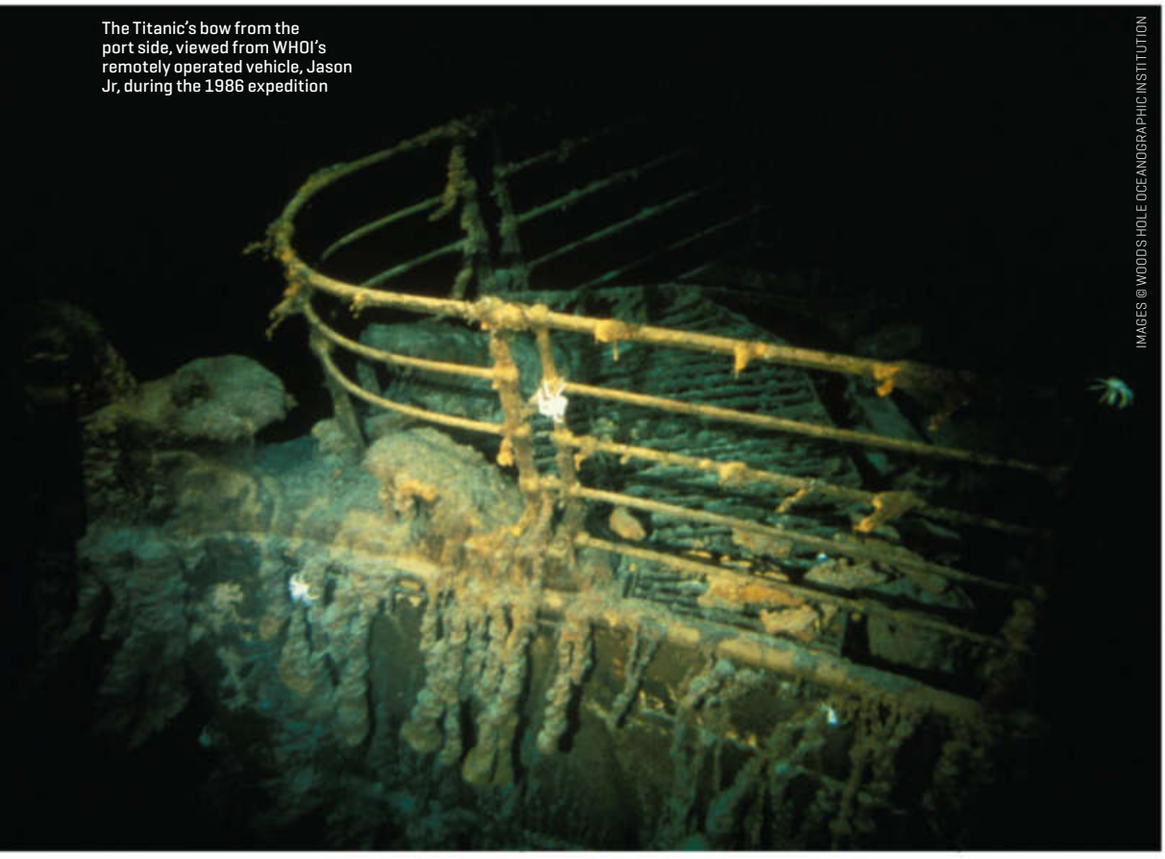
The Titanic, of course, never made it to New York. The ship was four days into its crossing of the North Atlantic when, at 11.40pm, an iceberg was spotted and the alarm raised. Less than a minute later, the Titanic had hit the ice. And less than three hours later, the Titanic lay 3,800m down, at the bottom of the Atlantic, having claimed more than 1,500 lives.

The wreckage, in two pieces, was eventually found about 600km from Newfoundland in 1985 by American geologist Dr Robert Ballard.

He was leading a Woods Hole Oceanographic Institution (WHOI) expedition funded by the US Navy, as part of a secret Cold War mission to find two wrecked nuclear submarines. Originally discovered using WHOI's unmanned camera sled Argo, Dr Ballard returned a year later in a manned submersible called Alvin.

The wreckage has since been revisited many times by a number of different researchers and experts, with approximately 6,000 artefacts – from dinnerware to the ship's whistle – being removed from the watery grave. It's estimated the fast-deteriorating wreck could totally collapse within the next 50 years.

Thankfully, the Titanic disaster was not a total waste of life. The sinking resulted in several major improvements to maritime safety, such as the requirement that all ships carry enough lifeboats for every single person on board.



The Titanic's bow from the port side, viewed from WHOI's remotely operated vehicle, Jason Jr, during the 1986 expedition

IMAGES © WOODS HOLE OCEANOGRAPHIC INSTITUTION

ABOVE The discovery team leaders from left to right: Jean-Louis Michel (IFREMER), Lt. George Ray (US Navy), Jean Jerry (IFREMER), Bob Ballard and Bernard Pillaud (IFREMER)

Andrew Westbrook
Science writer
+ Andrew is an experienced journalist based in the south-west of England. His extensive CV includes writing for a number of science titles around the world. ***@andy_westbrook***

RANDOM MATTER

Decompression sickness can be deadly

Dissolved gases in the blood can come out of solution and form bubbles, if decompression is done incorrectly

THE LIFE AQUATIC

How one man unlocked the secrets of the deep...

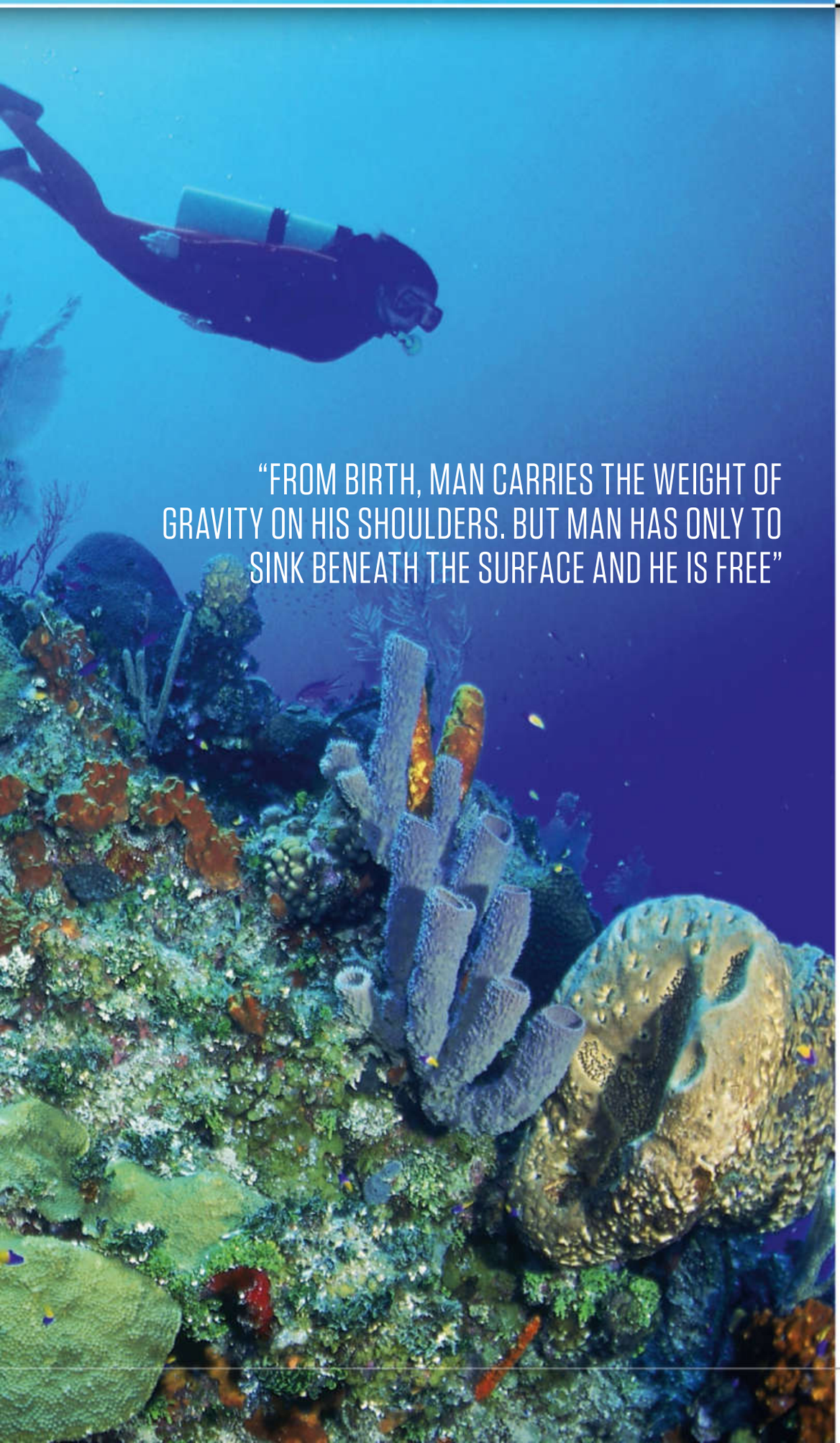
WORDS BY **David Boddington**

Today we're so used to seeing awe-inspiring footage from the deep oceans, and even visiting it ourselves more for amusement than exploration, it seems unimaginable that a little over 70 years ago this secret world was veiled by the limits of a lungful of air and a few atmospheres of pressure. It took the insight, vision and passion of one man to unlock two thirds of the planet for true exploration. That man was Jacques-Yves Cousteau: explorer, documentarian, naval officer and inventor of the Aqua-Lung. Born in rural France in 1910, Cousteau exhibited traits early in his childhood that would come to define his life and legacy. He learnt to swim at the age of four, and later on began to tinker with mechanical objects, to the point of even dismantling a video camera to see how it worked. Following his education, he joined the French Naval Academy and became a gunnery officer, before training as a pilot.

It was then in 1933 that his life and career took an unexpected turn, when

The deepest-ever SCUBA dive is 332.35m

It took Ahmed Gabr 12mins to r each the record-breaking depth, and 15hrs to safely return



THE DIVING **SAUCER**

Cousteau's vision needed a vehicle that'd make dreams become reality. And he found it in the Saucer...

+ The SP-350 Denise, more fondly known as the Diving Saucer, was invented by Cousteau and Jean Mollard at the French Centre for Undersea Research, and was first launched back in 1959. From Cousteau's flagship Calypso, the steel-constructed Diving Saucer was lowered into the water by crane. Measuring just under 3m in diameter, it has room for two crew members to lie down, and is able to safely reach depths of up to 350m, where it can remain exploring and filming for up to five hours at a time. Its construction allows it to resist pressure of 90 kg/cm^2 – equivalent to 900m below the ocean surface. Electric water jets supply propulsion, and an external manipulator arm can be fitted to allow the crew to pick up and examine objects. To date, the Diving Saucer has over 1,500 dives under its belt, and has spawned two smaller offspring - the Sea Fleas, which can operate at depths of 500m.

ABOVE The Diving Saucer was first launched back in 1959. Since then, it's racked up over 1,500 dives, extending human's knowledge of the oceans

RANDOM MATTER

Compressed air goes a long way

A 3-litre diving cylinder can carry more than 600 litres of air, as the gas is compressed at over 2,900 psi

he was seriously injured in a car crash. It prompted a move from the air to sea, and committed him to a career on and, before long, beneath the ocean waves.

While serving with the French Navy near Toulon, Cousteau would swim in the sea every day as part of his long rehabilitation. While there a friend gave him some goggles, giving him his first clear glimpse of the underwater world. His interest in the oceans had been piqued, but he still lacked the equipment to explore the depths with any real freedom.

WAR AND PEACE

After France surrendered to Nazi Germany in 1940, Cousteau moved to the town of Megève, in the shadow of Mont Blanc, where together with friends he developed the very first Aqua-Lung prototypes, also known as 'self-contained underwater breathing apparatus', or SCUBA. Standing on the shoulders of other aquatic breathing pioneers, they adapted a car engine fuel demand regulator, which allowed the flow of compressed air into the system to be driven by the diver's own breath requirements.

During this time, Cousteau made his first underwater documentary films, Par Dix-Huit Mètres De Fond (18 Metres Deep) and Épaves (Shipwrecks), and somehow found time to fight alongside the French Resistance, including working on a commando operation against Italian espionage operations. Later he won numerous awards for his bravery, including the Légion d'Honneur.

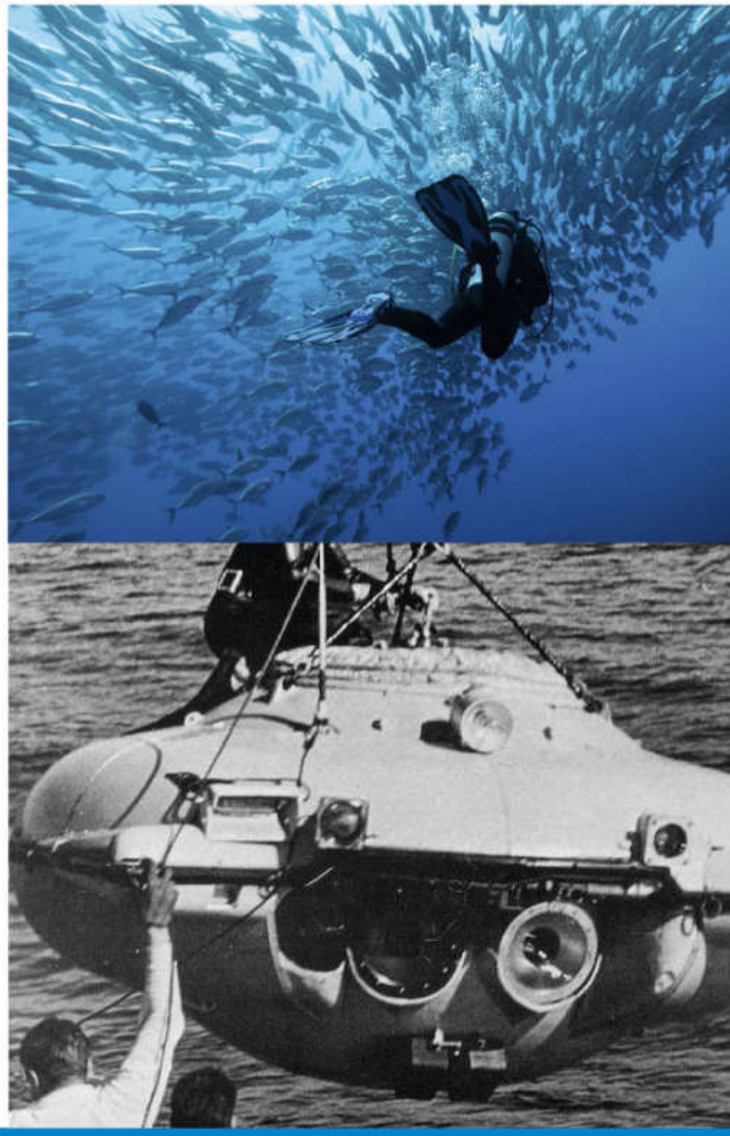
After the war was over, Cousteau and his colleagues were tasked with setting up the Underwater Research Group by the French Navy, clearing mines, carrying out experiments and making sub marine observations.

REWRITING HISTORY

In 1948, Cousteau went on an underwater expedition to explore the Roman shipwreck of Mahdia, first discovered by Greek sponge fishermen off the Tunisian coast in 1907, a project which ushered in a new age of underwater archaeology.

Shortly after, he left the Navy altogether, founded the French Oceanographic Campaigns organisation, and leased the now world-famous ex-minesweeper Calypso, which served as his floating base of operations for the coming decades. He also realised the importance of public opinion for the causes he felt so passionately about, publishing his first book, The Silent World, in 1953, later following it up with a film of the same name.

In the following years Cousteau continued his underwater exploration and ramped up his filmmaking, and in



DIVING EVOLUTION **THROUGH THE CENTURIES**

Man's come a long way since hollow reeds provided the primary aquatic breathing option...

SNORKEL

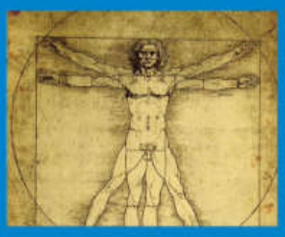
+ Herodotus records how around 500 BC, Scyllis, a prisoner of King Xerxes I, escaped the ship he was held on and, using a hollow reed as a snorkel, evaded recapture by hiding beneath the surface. At night he cut loose the moorings of every ship in Xerxes' fleet and swam to freedom.

CAULDRON

+ Around 350 BC, the Greek philosopher Aristotle recorded the use of a primitive diving bell saying, "They enable the divers to respire equally well by letting down a cauldron, for this does not fill with water, but retains the air, for it is forced straight down into the water."

GOGGLES

+ In the 14th century, Persian pearl divers were observed using simple goggles to protect their eyes. They were made not from glass but highly-polished tortoise shells. These were later imported into Venice and used by coral divers in the 16th century.



AIR TANKS

+ The world's greatest mind added air tanks to his list of inventions, when Leonardo da Vinci outlined their potential in the 15th century in his Atlantic Codex. He refrained from explaining them in detail, however, as he was concerned the technology would be used for nefarious ends.

The record for holding breath underwater is 22mins

Free diver Stig Severinsen also holds the record for the longest underwater swim of 500ft in 2:11mins

IMAGE © OFFICE OF THE OCEANOGRAPHER OF THE NAVY

Jacques Cousteau paved the way for innovators like James Cameron

IMAGE © BY PETERS, HANS / ANEFO

1959 launched his latest invention, the SP-350 Denise – also known as the 'Diving Saucer'. The first craft designed specifically for underwater scientific investigation, it helped Cousteau share the majesty of deep ocean life with the wider world. His filmmaking became truly prolific over the next few decades, and in 1968, he produced the first season of the hugely popular 'The Undersea World of Jacques Cousteau', alongside yet more documentaries and books.

A LASTING LEGACY

His desire to foster the understanding and protection of underwater ecosystems drove him to found the Cousteau Society in 1973. Following his death from a heart attack in 1997 aged 87, the Society has kept Cousteau's vision alive and to this day has more than 50,000 members around the world. As Roger Vidal of the society says, "The Cousteau society is the custodian of his vision. We follow his rules… Mission statement: to know, to love, to protect. Mission definition: Pioneer,Global, Perennial. Mission encouragement: Only impossible missions succeed [sic]."

Cousteau's technological developments opened up a whole new world for exploration and understanding, and his filmmaking brought them to a global audience.

DIVING SUIT

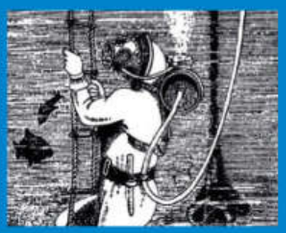
+ In 1715, the French aristocrat, inventor and sea-mad Pierre Rémy de Beauve crafted the first known diving suit. Complete with air-tight clothing, a metal helmet and two hoses, air was pumped through the system by bellows located at the surface.

REBREATHER

+ Napoleonic Naval mechanic Touboulic created the first oxygen rebreather system in 1808. His design used a gas reservoir from which the diver regulated the flow of oxygen through a closed circuit, with the carbon dioxide scrubbed by a sponge soaked in limewater.

DIVING HELMET

+ Charles and John Dean designed the first air-pumped diving helmet in 1829, using a fireman's water-pump for airflow and knight's armour which had been used to rescue horses from a burning stable. It was not a closed space, though, so there was a constant risk of flooding the helmet.



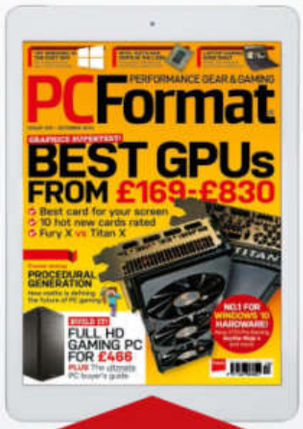
REGULATORS AND PRESSURE TANKS

+ In the 1860s, mining engineer Benoît Rouquayrol teamed up with naval officer Auguste Denayrouze to create a diving system using pressurised air tanks attached to a diving suit. This allowed divers to walk on the seabed at a depth of 10m for up to 30mins.

SCUBA

+ The first true open circuit SCUBA system was developed by Jacques Cousteau and Emile Gagnan in 1943, where the gas flowed from pressurised cylinders regulated by the diver's breathing, before being exhaled and released into the water. It ushered in a new era of diving.

SERIOUS ABOUT HARDWARE?



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THE ICEMAN

Lewis Pugh has become famous for cold-water swimming to highlight the plight of the world's oceans...

WORDS BY **JAMES WITTS**

On 3 March 2015, British endurance swimmer and United Nations Environment Programme (UNEP) Patron of the Oceans Lewis Pugh completed the most southerly swim in human history – just 10 days after setting the record for the first time. Pugh completed a 350m swim in the Bay of Whales, which lies in the Ross Sea in the Antarctic Ocean. "350m? Is that all?" you might ask. In the context of your local pool, it's hardly Neptunian. It becomes slightly more impressive when you consider sea temperature stung at -1°C against an air temperature of -37°C and a wind gusting at 75km/hr.

Pugh's Ross-Sea exertions were the latest in a series of swims in the Antarctic Ocean to encourage world leaders to make the Ross Sea a Marine Protected Area (MPA). Once Pugh had warmed up – the Ross Sea was so cold a wave that broke over his support crew froze on the crew – he revealed the motivation behind the death-defying swim.

"The Ross Sea is a place I care about," said Pugh. "It's the most pristine marine ecosystem left on Earth with wildlife found nowhere else and holds great scientific importance. Unfortunately, it's now being destroyed by industrial fishing. It leaves our children with a planet that's unsustainable."

Pugh's made it his life's mission to highlight environmental issues, specifically marine-based. In 2006 he became the first individual to swim the entire length of the River Thames, drawing attention to the severe drought in England and the dangers of global warming. It took Plymouth-born Pugh 21 days to cover the 202 miles, though he had to run the first 26 miles because of the drought.

But it's his cold-water exploits that he's become famous for. In 2007 he completed the first long-distance swim across the Geographic North Pole, swimming 1km in -1.7°C waters in just 18:50mins.

During his Arctic and Antarctic expeditions, scientist Tim Noakes observed Pugh's ability to raise his core body temperature by nearly 2°C when anticipating entry into frozen waters, coining the phrase 'anticipatory thermo-genesis'. It's a useful physiological tool as Pugh insists on completing these swims in nothing more than goggles, a swim cap and Speedos.

"I urge world leaders to do everything they can to protect our environment, but sometimes the legislation I request they enact is unpopular with the electorate," Pugh revealed in a Ted talk. "If I'm asking them to be courageous, I must also be. Swimming in a wetsuit wouldn't send the right message." DB

JAMES WITTS
Science writer
+James is a science and sports-science journalist based in Bristol. He's written for numerous science and sports publications around the world for 15 years.

ABOVE Lewis Pugh dives into the Ross Sea in early March this year. Water temperature was a chilling -1°C

IMAGE © LEWIS PUGH

RANDOM MATTER

The world record for breath holding is 22 minutes

It's held by freediver Stig Severinsen, who beat magician David Blaine's record of 17 minutes and four seconds

THE HUMAN FISH

How freedivers are stretching the physiological and psychological limits to swim deeper and for longer

WORDS BY **Andrew Westbrook**

Just how far can we push the human body? It's a question we ask ourselves constantly, in every possible way. But one of the purest tests is freediving – put simply, diving underwater while holding your breath.

Freediving is a practice that's existed for millennia. Archaeological evidence dating back to 5,400 BC suggests Scandinavians used it to collect shellfish, while Ancient Greece and Rome are both littered with references to people diving for food, salvage and even military reasons. In Japan, the predominantly female Ama (meaning 'sea women') have been known to dive for pearls for at least 2,000 years.

In recent decades, freediving has grown in popularity, with clubs operating under the umbrella of Swiss-based world federation AIDA, which runs competitions and keeps track of world records. Those records are split into eight disciplines. At one end is the Static Apnea discipline – the length of time someone can hold their breath while submerged. At the other end is No Limit – the maximum depth achieved on one breath, using weights and inflatables if desired.

Even for those not at the elite, record-breaking end of the sport, it's not hard to see the appeal. "It differs from scuba," explains Georgina Miller, clubs officer at the British Freediving Association. "There's less equipment, making it less cumbersome, and the silence means you can interact with wildlife much more closely. You can explore the underwater world in a totally different way, ascending and descending as often as you wish."

Emma Farrell, one of the world's leading freediving instructors, agrees. "When you scuba dive, the bubbles often scare away marine life, and you're limited with your movement," she says. "Freediving, you have a far greater interaction with wildlife.

The static apnea record is 11 minutes and 35 seconds

That was set by Stéphane Mifsud. AIDA doesn't recognise Severinsen's effort because he prepared with pure oxygen

EVIDENCE DATING BACK TO 5,400BC SUGGESTS SCANDINAVIANS FREEDIVED TO COLLECT SHELLFISH

FIVE OF THE BEST FREEDIVING SITES

There are a variety of options for breath-holding enthusiasts

1 DEAN'S BLUE HOLE

+ This water-filled sinkhole, off Long Island in the Bahamas, is thought to be the world's deepest blue hole with a depth of 202m. Essentially a vertical cave, filled with warm and calm waters, this is where many elite freedivers attempt to break a world record.

2 NEMO 33

+ Ideal for training and beginners, this 34.5m-deep indoor diving pool, in Brussels, Belgium, is the world's deepest. Often used for underwater filming, the complex was designed by diver John Beernaerts and features several simulated caves.

3 ROATAN

+ This small Caribbean isle off the Central American coast is surrounded by the Mesoamerican Barrier Reef, the world's second-largest reef system. It offers no shortage of deep drop-offs, plentiful marine life and wrecks to explore, all in warm, clear water.

4 CHEPSTOW

+ A flooded Gloucestershire quarry might seem an unlikely freediving destination, but it's where you'll find the National Diving and Activity Centre. It's also home to the UK's largest freediving group, SaltFree Divers. The NDAC's purpose-built freediving platform is the UK's deepest, going down 77m.

5 DAHAB

Infamously nicknamed the 'Diver's Cemetery', for the estimated 100-plus scuba divers to have died there since 2000, this 130m-deep blue hole, near Dahab, on the Red Sea, is one of the world's most popular freediving sites. At 56m is 'the arch', a 26m-long tunnel leading out to the open sea.

RANDOM MATTER

Freedivers' heart rates can drop to 10bpm

This starts with the 'mammalian effect', which sets in as soon as your body touches cool water

IMAGES © HERBERTNITSCH.COM; FRANCINE KREISS; THINKSTOCK

ABOVE Herbert Nitsch and the powered sled he used on his No Limit dive to 253m

RIGHT Record-breaking freediver Nitsch admires the view at Dean's Blue Hole in the Bahamas

Animals are attracted to you – they come and check you out – plus you have far more freedom of movement under the water."

PHYSICAL AND MENTAL BENEFITS

Freediving also has many mental and physical benefits. It teaches you to breathe correctly, which lowers heart rate and calms the nervous system. Learning how to use the diaphragm, lungs and rib cage also increases vital capacity (maximum capacity of air inspired in a single breath).

Naturally, adds Farrell, the sport is not without its challenges. "Firstly, you need to overcome equalisation (balancing pressure inside and outside ears), but there are also lots of things you can do to help equalisation issues, such as diet, cranial osteopathy and sinus washing," she says. "But yes, doing this quickly, and head first, can be the biggest physical challenge for people new to freediving. They think that the ability to hold your breath will be a limiting factor, but everyone can hold their breath far longer than they think.

"In fact, the biggest limiting factors are to do with the conscious and unconscious mind. Most people will be very scared of depth, underwater life and the sensation of holding their breath. But pretty much every physical hurdle can be overcome. Practice is key, as well as training with someone you completely trust."

Still, even with those challenges ticked off, the sport isn't without its risks. While freediving is safe when conducted properly, and should never be done alone, the physiological hurdles associated with functioning on very low levels of air, and at depth, where the atmospheric pressure roughly doubles every 10m, are not to be underestimated. It's not surprising that, to many, it falls squarely within the 'extreme sport' bracket, with August's tragic disappearance – presumed death – of world champion freediver Natalia Molchanova offering a stark reminder.

ABOVE A major risk is suffering shallow water blackout syndrome, during the ascent

"There are many risks," says Dr Mark Turner, cardiologist at Bristol Royal Infirmary and vice-chairman of the UK Sports Diving Medical Committee, who was formerly a submarine escape instructor for the Royal Navy. "But most of them only apply to the superstars pushing the limits. For club divers, the primary risk is shallow water blackout syndrome. Ear problems are also quite likely." Shallow water blackout syndrome is the result of us needing less oxygen at depth, due to the higher pressure, which can result in divers not leaving enough in reserve for when they ascend. As the diver rises, pressure in the blood eases, but there's no longer enough oxygen. With no warning, hypoxia occurs.

"It's the cause of most freediver deaths," continues Dr Turner. "They're at 2m, black out, then sink and drown.

Freediving is often called apnea

The name derives from a Greek word meaning "without breathing"

Q&A ALICE HICKSON

One-on-one with the No Fins gold medallist from the 2015 freediving world championships

How have you gone from novice to world champion in nine months?
I just enjoy what I do. I love the peace and tranquility. Once submerged, it's like nothing matters. All thoughts and feelings are washed away... until I need to breathe again!

How do you prepare?
Being physically fit is one thing but you have to be mentally up to the challenge, too. A lot of freedivers meditate and practise yoga to help free the mind of distractions and to enter a more mindful state, so they can focus on their breath and stay relaxed.

What happens when you're running out of air?
Common are contractions of the diaphragm – some people say it's like been punched in the stomach. It's a good indication you may be reaching your limit. Psychologically, I think you just have to keep yourself calm, but it's also vital to tune into the physical indications your body gives you.

Such as...?
People might start to feel a burning sensation (build-up of lactic acid) in their muscles, or they can't think clearly. Once you're not thinking straight, it's definitely time to surface. It's important to only increase distances a few metres at a time because there's no definitive way of knowing exactly when you need to breathe. The ideal is to do things gradually and stay within your limits – it's a very thin line between blacking out and finishing a dive 'clean'.

Alice Hickson swam 174m without breathing to secure a gold medal and British record

A LOT OF FREEDIVERS MEDITATE AND PRACTISE YOGA TO FREE THE MIND OF DISTRACTIONS AND ENTER A MINDFUL STATE

There's simply not enough oxygen left to sustain the brain."

AVOID THE LUNG SQUEEZE

That danger can largely be eradicated by diving sensibly and with others. But it's a different story for the superstar divers pushing the limits. For them, a host of other issues come into play.

"Lung squeeze is the factor that will likely limit the maximum depth a freediver can achieve," explains Dr Turner. "The deeper you go, the more the lungs are squeezed. At 190m, and 20 atmospheres, lungs that are 10 litres on the surface will be down to 500ml. The lungs are squashed; there's close to no air; and the airways and alveoli (air sacs) stick together."

As divers go deeper, for longer, then issues familiar to scuba divers become a factor. For instance, decompression sickness caused by a build-up of nitrogen bubbles in the body. Or pulmonary barotrauma, when a diver breathes at depth, then ascends too quickly – the gas expands, rupturing the lungs.

One man aware of the risks is Austrian Herbert Nitsch, aka the 'deepest man on Earth'. His CV includes 33 world records across all eight freediving disciplines, including the big one – No Limit. He secured the record, using a powered sled, with a dive to 214m. Then, in 2012, in an achievement not recognised by AIDA due to a sponsorship dispute, he made it to 253m. But disaster struck. He suffered severe decompression sickness resulting in multiple strokes.

His road to recovery has been long and slow, including six months in a wheelchair, but he's back diving again. He tells us how it was, in part, the buccal pumping technique that helped him go so deep. "Buccal pumping is packing the lungs with additional air using the epiglottis as a piston. You extend your lung volume above its normal capacity – you can increase it substantially with certain stretching exercises. For example, my lung volume increases from 10L to 15L with packing. The additional air for deep diving is mainly used for the equalisation of the sinuses and Eustachian tube (ears)." Like Farrell, however, Nitsch stresses it's the state of mind that's all-important.

"Psychological dangers are related to the physiological ones," he says. "You have to be relaxed, as if you just woke up on a lazy Sunday morning."

So how much further can divers push the records? Medical experts suggest the limits aren't far off, but Nitsch is a man used to confounding medical experts. "It's getting more dangerous," he concludes, "but there is no limit." DS

Andrew Westbrook
Science writer
+ Andrew is a keen scuba diver and has written for numerous publications in the UK, US and Australia. *@andy_westbrook*

SCIENCESHOT

+Stunning images from the Earth's oceans

GOOGLE GLASS BOTTOM BOAT

Online behemoths are taking the search underwater to highlight the plight of the world's corals

PHOTO © CATLIN SEAVIEW SURVEY

+ Not content with dry land, Google has expanded its Street View project to the underwater world. To create the images, the technology giant teamed up with the XL Catlin Seaview Survey, a major scientific study of the world's reefs. The Survey uses its specially designed underwater camera, the SVII, to capture the GPS-located shots in high-resolution, panoramic vision. The camera takes quick-fire 360° images every three seconds, while travelling at about 4km/hr. The images are then stitched together to allow users to self-navigate and take a virtual dive.

TO CREATE THE IMAGES, THE TECHNOLOGY GIANT TEAMED UP WITH THE XL CATLIN SEAVIEW SURVEY, A MAJOR SCIENTIFIC STUDY OF THE WORLD'S REEFS

The XL Catlin Survey began in September 2012

It's since visited 25 countries and collected more than 700,000 panoramic images

+ A bumphead parrotfish poses for the Catlin camera in this flattened 360° image of the coral-covered wreck of American cargo ship the USAT Liberty, off Tulamben, in Bali.

RANDOM MATTER

Film director James Cameron has visited the Challenger Deep

In only the second trip to the world's deepest point, he recorded footage for a documentary

EXPLORING THE OCEAN

From the surface to the deepest sea trench, this is the technology that enables us to discover more about the oceans

WORDS BY **Matthew Bolton**

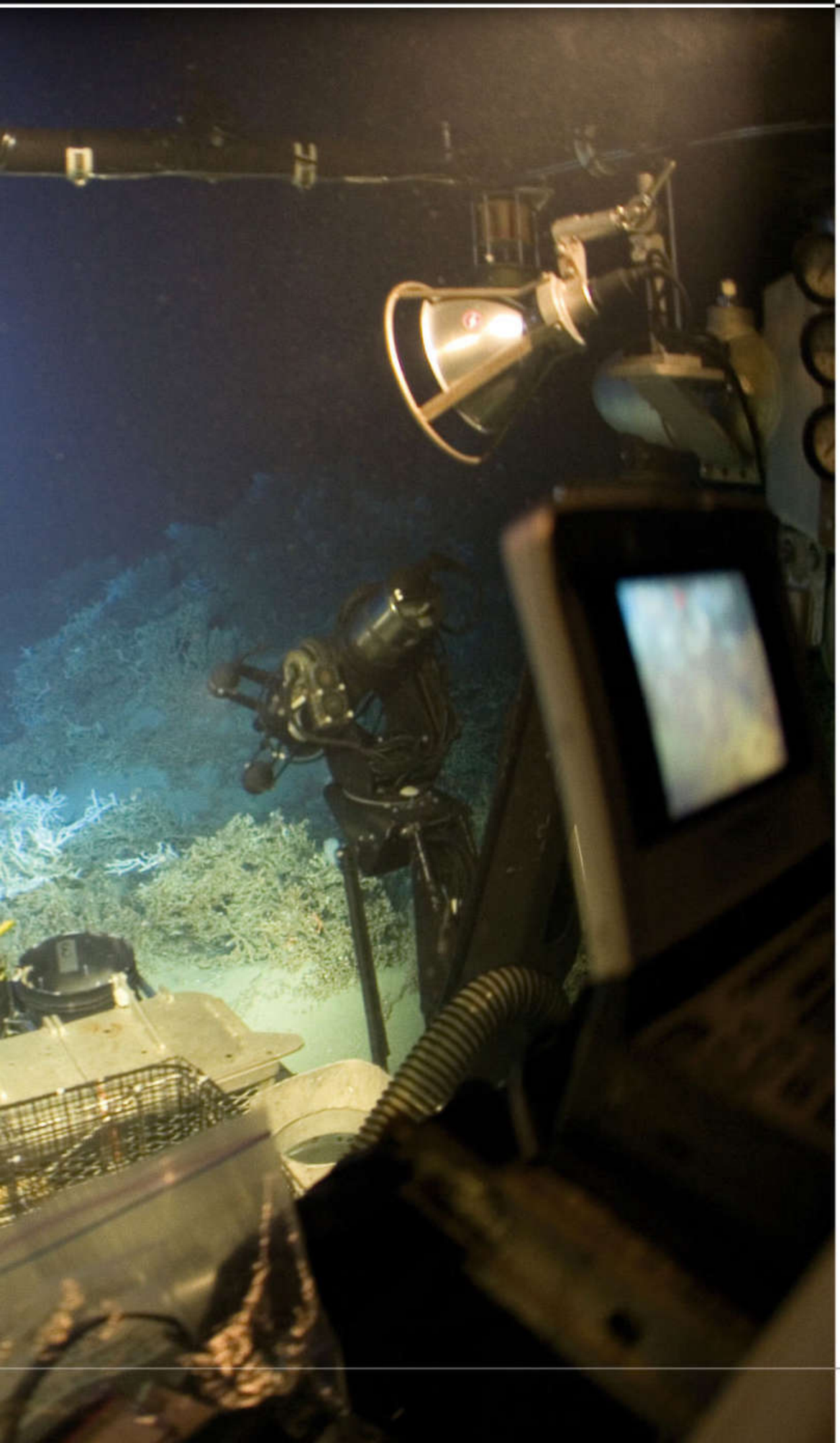
The ocean is huge. The vastness of its surface is ingrained into us from years of seeing maps and globes, but the surface is only half the story. When we talk about exploring the ocean, we're talking about its entire volume – all 320 million cubic miles of it. It's estimated that we've really explored about just 5% of that – so there's lots still out there for us to learn.

But that's not to say we don't know things about the ocean at large, even if we haven't explored most of it in depth yet. There are two key ways for us to grow our knowledge: one is to understand the ocean we're familiar with better; and the other to explore its untouched and inaccessible areas.

We're getting much better at the first of those two thanks largely to leaps forward in technology. Cheaper, smaller, more ubiquitous electronics and wireless communication advances mean that we be more flexible and widespread in how monitor and learn about the ocean. "The biggest advances in deep-sea exploration are

Cameron's Deepsea Challenger vessel was made of 70% foam

'Syntactic foam' comprises glass microspheres in resin. It's strong and buoyant



SELF-CONTROLLING SUBMARINES

How smarter autonomous underwater vehicles could help us to speed up learning about the ocean...

+ Underwater robots can help us to map or study areas of the ocean very effectively – but they have some major disadvantages. If acting autonomously, they can't react to something unexpected and in the way a human can, meaning they require a lot of prepared programming, especially as they're usually sent out on solo missions. Engineers at MIT have developed a way to give underwater robots more autonomous "cognitive" capabilities, letting them make their own decisions about how to execute a task after being given their overall goals. Designed to operate in groups, you could let a group of deep-sea drones collect samples and map areas, all communicating with each other to cover an area as efficiently as possible – avoiding collisions and reprioritising tasks based on time constraints. They'd require much less programming and monitoring, while collecting more data. They might not be a substitute for sending a human to an unexplored area, but they could give us much more information than we could otherwise collect.

ABOVE Self-controlling submarines that communicate with each other are the future of mapping the Earth's oceans

RANDOM MATTER

Only one unmanned vehicle can operate past 10,000m

The Japanese probe ABISMO visited the Challenger Deep in 2008, collecting samples

closely aligned to those we have seen on land," explains Liz Taylor, President/CEO of DOER Marine, who create deep-sea exploration vehicles and equipment. "More processing power in smaller packages, faster data transmission, better data storage and transfer technology, and so on."

TECHNOLOGICAL DRIFTERS

We can spread a wider net of ever-more sensitive and complex scientific equipment, yet more manageable sizes. For example, to understand the extremely complex nature of ocean currents, we can use tools such as 'Drifters'. These are simple flotation devices, designed with a large area beneath the surface to ensure that they're carried well by the currents, with a satellite transmitter on board. They periodically sends their location to the satellite, which sends it on to be collated with information from Drifters, and other sources of data, to build a more detailed picture of current movement across one sea.

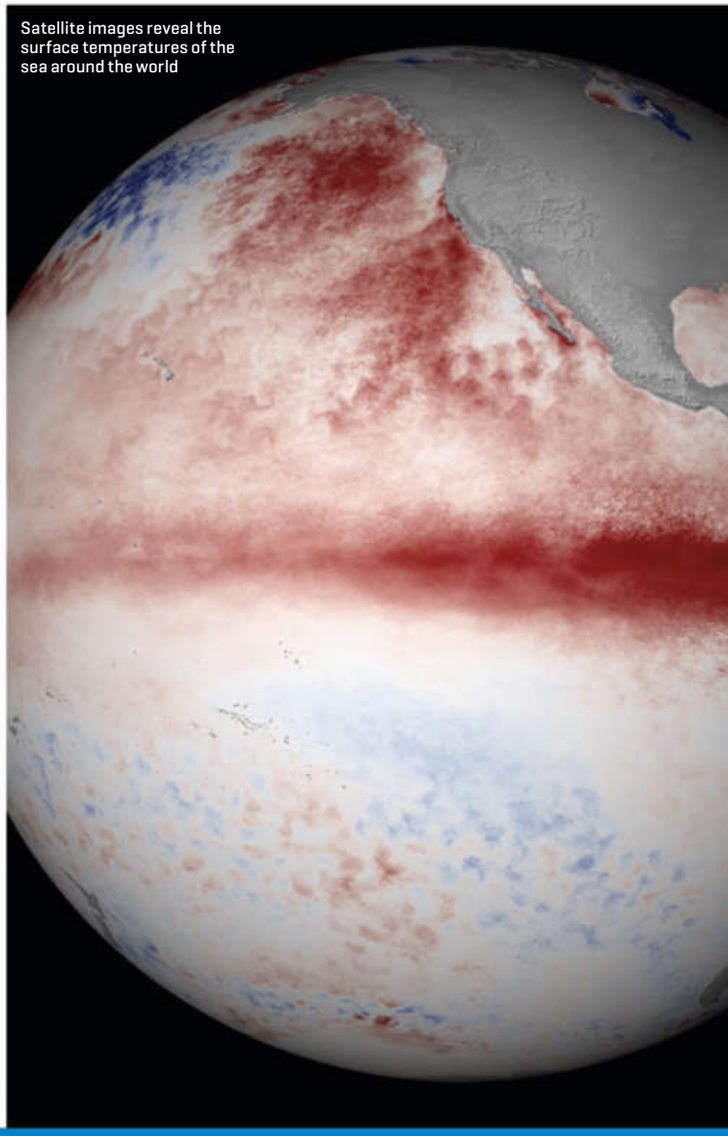
Mapping the ocean floor is easier than monitoring the currents, but its still vast. Its entirety has been mapped to a resolution of 5km (so we can see things that are 5km or larger), but that leaves almost all the detail out. Ships with advanced sonar equipment have mapped around 15% of the ocean floor in much greater detail, building 3D models of its shape – but still at a resolution of around 100m.

Satellites have helped us to build maps of the ocean floor, too. Though they can't see 'through' the water with radar or any similar system, they can track the height of the sea very accurately. By averaging those results, we can see changes in its surface that result from underlying topography.

Still, to see what's underneath the surface in real detail, you need to go there. There are now submersible vehicles capable of reaching many depths, and even an underwater lab in Florida, named Aquarius, for studying the reefs. With all this technology, we can monitor and understand a lot of the ocean… but we're still relatively blind to its deepest extremes.

CHALLENGER DEEP

The Challenger Deep is the ocean's deepest point. At its deepest point it reaches around 10,900m below the surface. The pressure at that depth is incredible – around 8 tons per square inch, which is over 1,000 times the pressure of the atmosphere at sea level – which could simply crush vessels without strong enough bodies if they try to descend that far. Only two manned missions have ever been there, in 1960 and 2012. More missions are planned, including one named Deep Search, in a vessel designed by



Satellite images reveal the surface temperatures of the sea around the world

TECHNOLOGY TO **MONITOR THE OCEAN**

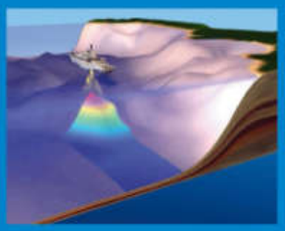
We use many different methods to paint a better picture of the infinite complexity of the Earth's oceans – from simple floating GPS units to satellites

HYDROPHONES

+ These underwater microphones are used to monitor things like whale movements or volcanic eruptions. There are several stationary arrays in the Pacific, but mobile units are used, too, often revealing fascinating insights into animal behaviour or seismic activity.

ADCP

+ Acoustic doppler current profilers (ADCPs) are placed on ships or the ocean floor, and emit audio pulses. When these bounce back to the ADCP, their pitch will have changed, depending on whether water's moving towards or away from the ADCP, allowing us to monitor the currents at depth.

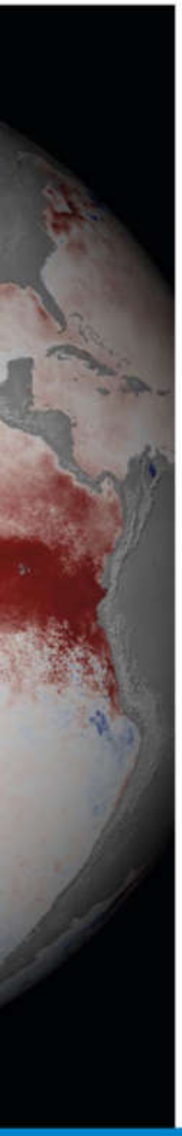


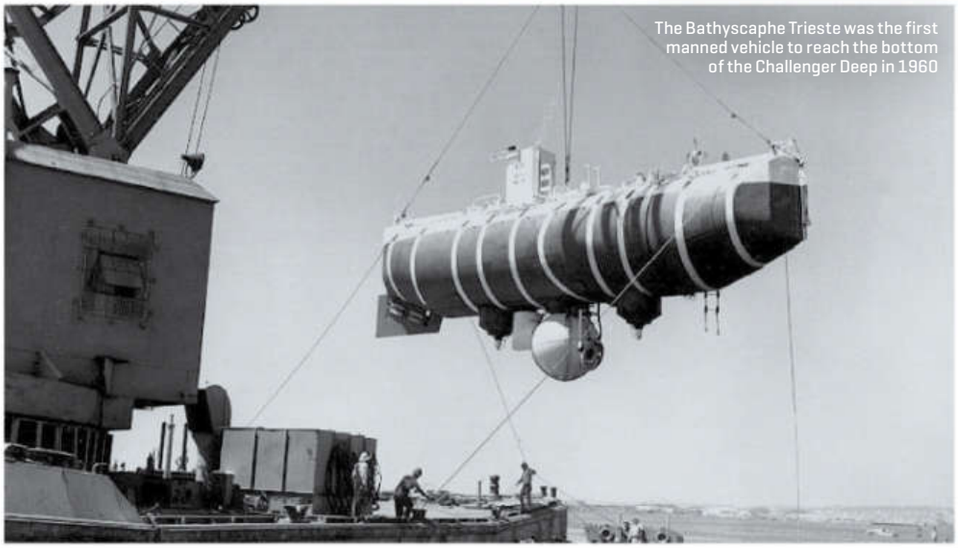
SONAR

+ Bouncing sound off objects has been used since World War I. Vessels will often carry two kinds of SONAR: 'side-scan' SONAR is great at detecting objects or materials on the sea floor, while ship-mounted 'multibeam' systems are better at gathering 3D height map data.

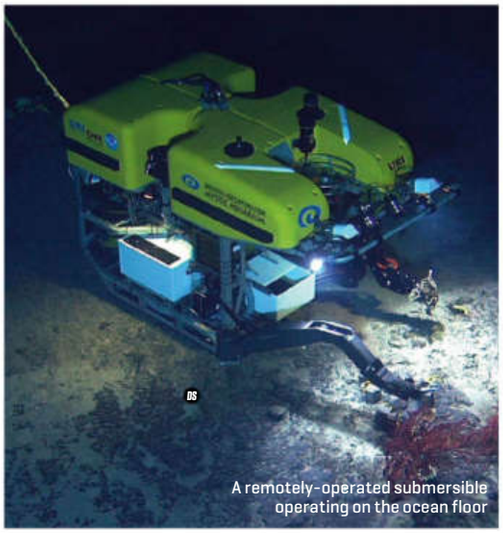
Glass of just 10–15cm protects at great depths

The added pressure of deep water means even an impact would fail to crack it





The Bathyscaphe Trieste was the first manned vehicle to reach the bottom of the Challenger Deep in 1960



A remotely-operated submersible operating on the ocean floor

Liz Taylor's team at DOER. "The advances in materials have been significant, not only in terms of new alloys and materials but also in our ability to observe and understand these materials under various conditions, even to the molecular level in some cases," explains Taylor. Interestingly, one of the materials being used is simple glass, because it actually becomes stronger when placed under pressure – a glass sphere would be able to withstand extreme forces, provided it has no weak points.

For DOER, the focus is on getting work done while down in the Challenger Deep. "The people are the most important asset but, beyond that, the sampling tools are crucial," says Taylor. "They're manipulators that allow discrete collection of sediment, rocks, corals, sponges and more."

You might think the sampling could be automated, meaning an unmanned vessel could go down instead, but Taylor reiterates the importance of having people visit the bottom: "It has been said that 'one cannot surprise a robot'. People are by nature explorers and story tellers. Having the ability to explore and observe directly in the sea at any depth is a fundamentally richer experience than relying only upon a robot's cameras and sensors."

SUBMERSIBLES

+ Submersibles will usually be fitted with articulated mechanical arms for collecting samples, allowing us to bring the ocean floor up to ship or land-based labs for study. Some are meant only for light depths, while others, such as the Mir I and II vessels, can reach 98% of the ocean's floor.

DIVERS

+ Humans can only reach around 110m safely, even using special air mixtures. However, there are Atmospheric Diving System suits that survive at over 600m deep – though these suits are more like human-shaped submarines, offering little fine control or interaction with the world.

NETWORK OF SCIENTIFIC VESSELS

+ Many ships will have on-board labs; some will have remotely-operated vehicles for sample collection. They'll also monitor atmospheric data, and may have cranes and frames for supporting a wide range of other monitoring equipment.

REAL-TIME COMPUTING

+ The ability to collate and reference data is vital. Fleets of vessels will collect a variety of atmospheric, navigational and biological data from many different areas, and being able to process the data or just reference it anywhere gives vital context to scientific ventures.

SATELLITE MONITORING

+ Satellites are used for many purposes, including mapping the ocean's floor. Satellites are also used to monitor sea temperatures, which elicits vital information, from understanding weather to fish movement. Satellites also look out for events such as algal blooms.

RANDOM MATTER

Alexandria was lost for 1,600 years

Marine archaeologists found the land of Egyptian ruler Cleopatra in 1998, just off-shore from modern-day Alexandria

UNDERWATER METROPOLIS

Will people ever live in the water en masse? Maybe – but it's not as simple as just building some skyscrapers

WORDS BY **Matthew Bolton**

With the population of the Earth expanding, but the amount of habitable land staying the same, we may need to look at alternative options for housing people in the future.

Looking to maximise the vast space of the ocean is Shimizu Co, a Japanese company that's investigating several potential possibilities for human habitation. Its latest proposal is a concept known as the Ocean Spiral, which suggests a way for humans to live sustainably in water.

The Ocean Spiral comprises three key parts: a sphere that provides the main living space in a large central column; a spiral leading from the sphere to the ocean floor, which would house equipment for things like power generation and desalinating water; and a 'factory' facility located on the seabed, which would manage carbon dioxide levels and could extract mineral resources from the sea floor.

The idea is that the sphere generally floats partially above the surface, providing it with plenty of natural light through its clear panels. A protective ring would break up waves, but if a storm comes, the entire sphere could be submerged through the use of vast adjustable ballast units. Though Shimizu refers to it as a city, each Ocean Spiral is intended to house around 4,000 people permanently, with space for 1,000 visitors, with potentially many existing near each other in a network across the world.

However, while Shimizu believes it may be possible to build the Ocean Spiral in around 15 years' time, there are many technological hurdles ahead. These vary from building a strong enough sphere, to maintaining a comfortable atmosphere within, to working out vibration dampening at that scale. There are social elements to consider, too. In its current designs, Shimizu suggests that office and scientific facilities can be used for oceanographic research, but if there were many of these cities, they'd need to think about how to best use the space for other industries or business, and decide how best to arrange people's living space accordingly.

It's not quite the idea of the vast deep-sea metropolis we might expect from the idea of an underwater city, but it's exciting to think about the possibilities for environmentally sustainable, safe ways to live out in the oceans. DS

AQUARIUS UNDERWATER LAB

US research beneath the waves

+ Though we're nowhere near anyone permanently living underwater, people have spent a considerable amount of time in ocean habitats temporarily. Aquarius Reef Base is a small laboratory and living space, built to study the reefs of the Florida Keys, that sits 19m beneath the surface. Most scientific missions in it last around 10 days, but Fabian Cousteau, son of Jacques, spent 31 days living there with his crew in 2014, gaining vast amounts of scientific data.

THE BLUE GARDEN ATRIUM

The sphere is known as the Blue Garden, and its central column structure houses around 1,100 apartments or residences, 10,000m^2 of retail space, 50,000m^2 of offices and 140,000m^2 of research facilities. The equivalent of 75 floors from bottom to top, the sphere has several promenades and observation gondolas that move up its inner edge, giving riders a view of the ocean.

SUPER BALLAST BALLS

Three vast balls tethered to the bottom of the sphere are designed to provide adjustable ballast. Each is filled with sand, but can then be optionally filled with air to adjust buoyancy. During typhoons, the sphere would be made to sink safely underwater. Or during maintenance to its exterior, it could be made to rise higher out of the water. It's a simple solution for adding height control, though still an engineering challenge in itself.

TENSION LEGS

To avoid the sphere drifting and pulling the spiral apart, the city would be moored to the sea floor by structures running the entire height of the spiral. These connect to a ring at the top of the spiral, which is in turn connected to the top-most ballast ball, which is connected to the sphere.

The longest time spent underwater is 73 days

Teachers Bruce Cantrell and Jessica Fain hosted 'Classroom Under The Sea' programmes via YouTube

DESIGNERS SHIMIZU BELIEVE IT POSSIBLE TO BUILD OCEAN SPIRAL IN 15 YEARS' TIME, BUT THERE ARE MANY HURDLES AHEAD

AQUACULTURE

Part of making the city self-sustaining would be food generation. While it may be possible to cultivate algae and grow other foods that way, there's also the potential for sustainable fisheries. Large culture ponds can be created in the sea directly, with nutrient-rich water pumped up from deeper in the sea and the temperature easily controlled, while 300m high walls would be used to keep the fish in. Without a floor, their waste would simply sink into the sea, keeping the area clean, but the fish wouldn't escape as many just couldn't reach that depth.

FLOATING SEA WALL

A disruptive ring floating comfortably around the Ocean Spiral is designed to stop major waves from giving it any problems during day-to-day use. The sea wall will also stop shipping reaching the city. It can also act as a terminal for large passenger ships, with people then able to make their way to the Blue Garden's Grand Entrance via smaller boats within the ring.

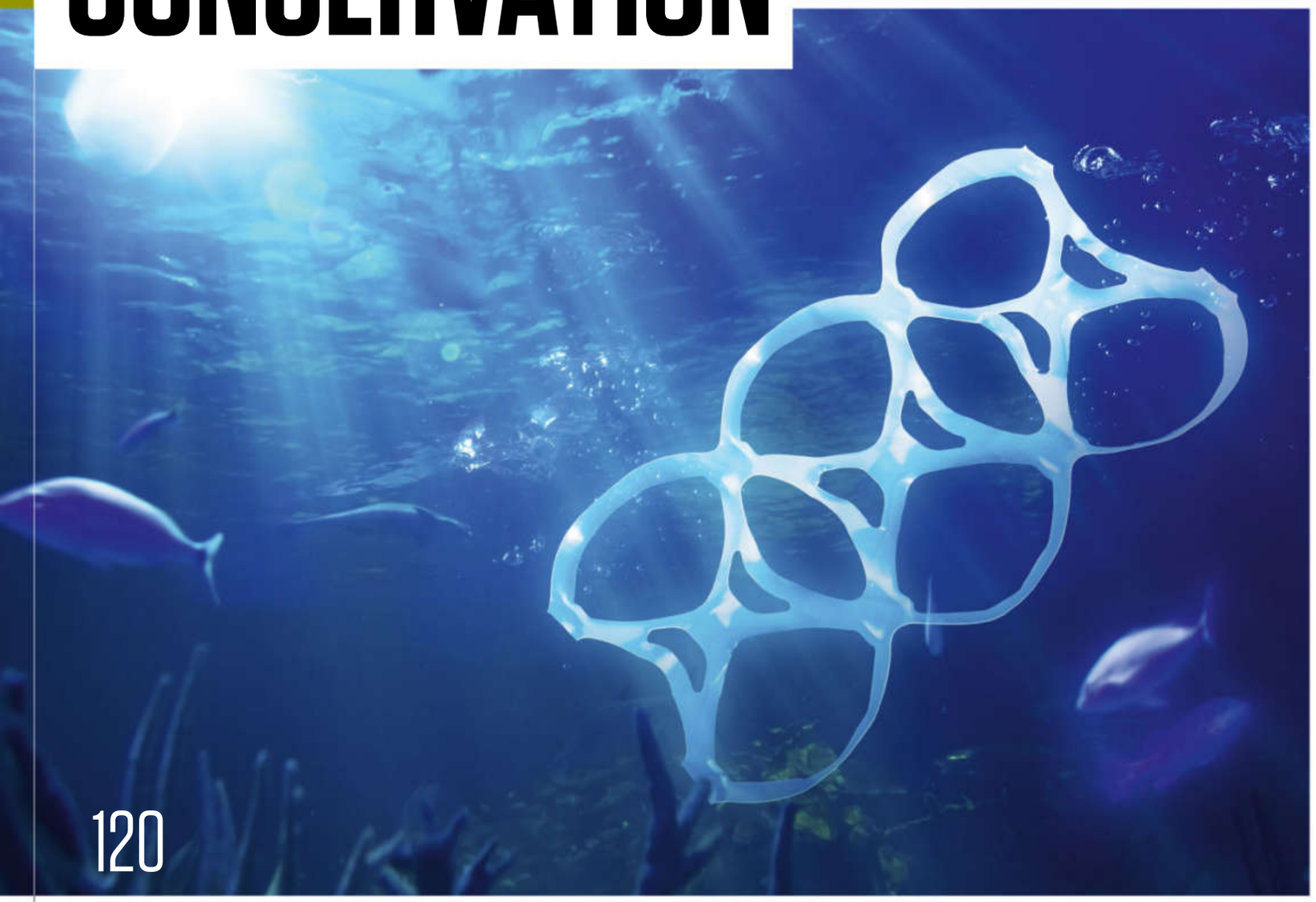
DEEP-SEA GONDOLAS

Gondola trains would run along the edges of the Infra Spiral, taking people to and from the facilities located deeper in the ocean. The plan is to include docking stations for submersible vessels at around the 2,500m mark, so this would allow passengers to go from those vessels to the Blue Garden. It also provides access for maintenance or research purposes to the equipment down the spiral and on the sea floor.

INFRA SPIRAL

The spiral, winding from the sphere to the ocean floor, serves many vital functions. It houses equipment at 2,500m deep for creating fresh water, using the pressure of the deep ocean to force water through a semi-permeable membrane that filters out the salt. It would also generate electricity, using 'ocean thermal energy conversion', where the difference between water temperatures at different depths is exploited to generate water vapour that drive turbines.

CONSERVATION



"SLAT'S SYSTEM TO CLEAN UP PLASTIC IS 7,900 TIMES FASTER THAN NORMAL"

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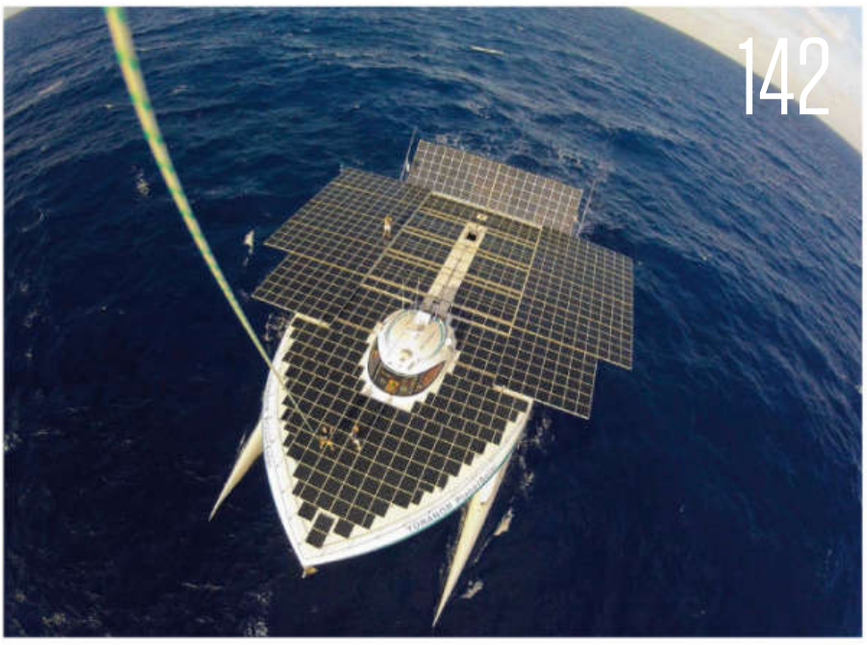
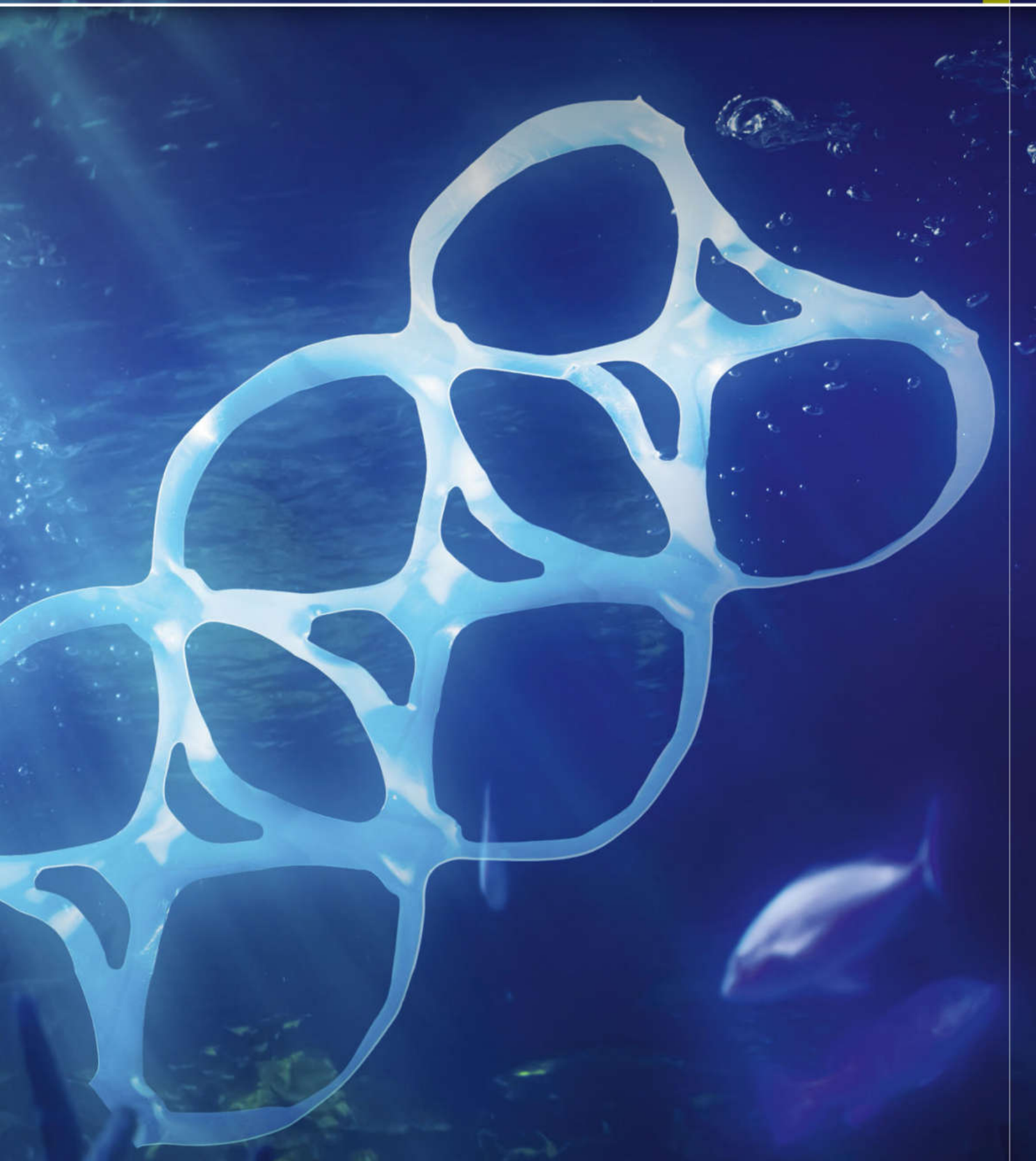


10 WAYS TO MOP UP OCEAN POLLUTION

Oil spills and plastic debris are perhaps the biggest threats to our oceans. Here are 10 ways that humans try to limit their devastating effects

WORDS BY **TIM HARDWICK**



RANDOM MATTER

Pollution stimulates blooms of algae

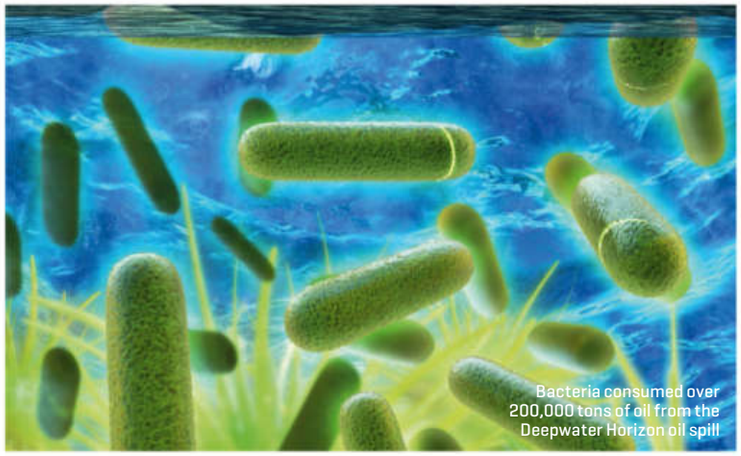
So deep is the problem that emanates from sewage discharge and industrial run-off that NASA has named them 'creeping dead zones'

10 OCEAN BACTERIA

One of the best defences against oil spills is forged by Mother Nature herself

Astonishingly, recent marine research revealed that naturally occurring bacteria ate up over 200,000 tons of ocean contamination that spewed into the Gulf during the 2010 BP Deepwater Horizon oil spill. This makes sense when you consider that oil is a natural product made from decayed plants and animals, which are bacteria's bread and butter. However, data showed that the bacteria's appetite slowed five months after the explosion that set off the environmental disaster. Microbiologist Joel Kostka from the Georgia Institute of Technology explains why. "Because oil is low in nutrients such as nitrogen, this can limit how fast the bacteria grow and how quickly they are able to break down the oil," he says. "However, our research has shown that some bacteria are able to solve this problem themselves by extracting their own nitrogen from the air."

FERTILISATION IS FAST BECOMING A PRIMARY TECHNOLOGY IN MODERN EFFORTS TO CLEAN UP OCEAN POLLUTION SPILLS



Bacteria consumed over 200,000 tons of oil from the Deepwater Horizon oil spill

Kostka analysed over 500 samples taken from beaches in the Gulf of Mexico when the Deep Water Horizon oil slick first came ashore in June 2010. By examining the bacteria, he was able to isolate which genes are responsible for transforming nitrogen into inorganic compounds usable by plants. Kostka found that some bacteria supplemented their diet with nitrogen, and believes that this discovery could lead to far more effective clean-up techniques. Indeed, fertilisation – the method of adding nutrients to a contaminated environment to stimulate the growth of microorganisms – is fast becoming a primary technology in modern efforts to clean up ocean pollution spills, coining the term 'bioremediation'.

IMAGE © DANIEL AZOCAR

ABOVE Booms are the most common method of curtailing the spread of pollutants such as oil slicks. They're a proven method of containment, though have limitations when the waves rise

BOOMS SERVE TO CHANNEL OIL INTO THICKER POOLS TO MAKE IT EASIER TO REMOVE FROM THE OCEAN SURFACE

9 FLOATING BARRIERS

They may seem rather parochial but they're an effective way to contain oil

Perhaps the most common feature at sites of accidental oil spillage is the use of floating barriers or 'containment booms' – long perimeter lines that float on the water's surface around the affected area. Booms are the most effective system for quickly limiting the spread of an oil slick, which reduces the possibility of polluting shorelines. Booms also serve to channel oil into thicker pools to make it easier to remove from the ocean surface. What's not so obvious from above is that booms wear 'skirts' to aid the underwater containment process. These can measure between 18 to 48in long and function well in calm seas but, as waves grow, bigger contaminants can penetrate the skirt and render the boom useless.

To guard against this, a chain or cable known as a 'longitudinal support' often runs along the bottom of the skirt to strengthen the boom against wind and waves, and also acts as an anchor. Some booms are non-rigid or inflatable, making them easier to clean and store. They also tend to operate better in turbulent waters but, ultimately, the higher the waves rise, the less effective booms become.

To counter these conditions, some booms are fixed to a structure such as a pier, or towed between or behind boats, albeit slowly to avoid drainage failure.

8 OIL SLICK SKIMMERS

Following in the slipstream of the booms are an array of skimmers

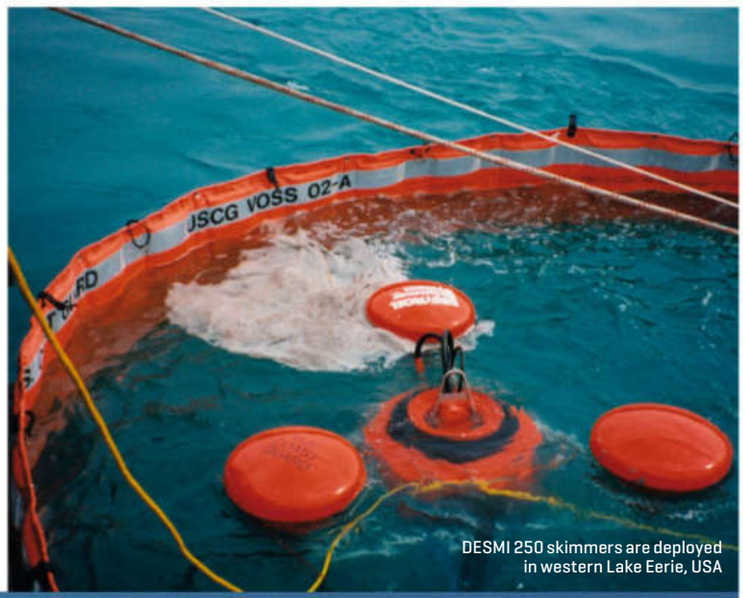
After containment booms, skimmers are often the second line of defence in the battle to clean up oil spills. Skimmers work to recover oil that gathers on the ocean surface and can be self-propelled or operated from ships.

As with booms, the performance of skimmers is dependent on conditions at sea. For instance, when operating in turbulent seas, skimmers tend to recover more water than oil. Three models of skimmer, in particular, have proved their worth in various scenarios.

Weir skimmers come fitted with a dam or enclosure where the oil and water meet. The idea is that oil floating on the surface of the water spills over the dam and gets trapped in the well inside without bringing over too much water. The captured liquid can then be pumped out through a pipe to a storage tank and recycled for disposal. The disadvantage of skimmers is that they can become clogged up by debris. Oleophilic or 'oil-attracting' skimmers mop up oil from the surrounding water through the use of belts or absorbent chains of oleophilic materials. The oil is then squeezed out or scraped off into a recovery tank. Oleophilic skimmers perform well whatever the oil thickness and can stand up to most debris.

Suction skimmers work like giant vacuum cleaners and suck up oil through floating heads into a recovery tank. This makes them extremely efficient on calm water, but also the most vulnerable to clogging up.

AS WITH CONTAINMENT BOOMS, THE PERFORMANCE OF SKIMMERS IS HIGHLY DEPENDENT ON CONDITIONS AT SEA



DESMI 250 skimmers are deployed in western Lake Eerie, USA

IMAGE © US COAST GUARD

7 SORBENTS

These versatile 'mops' contain the absorbent capacity of a sponge

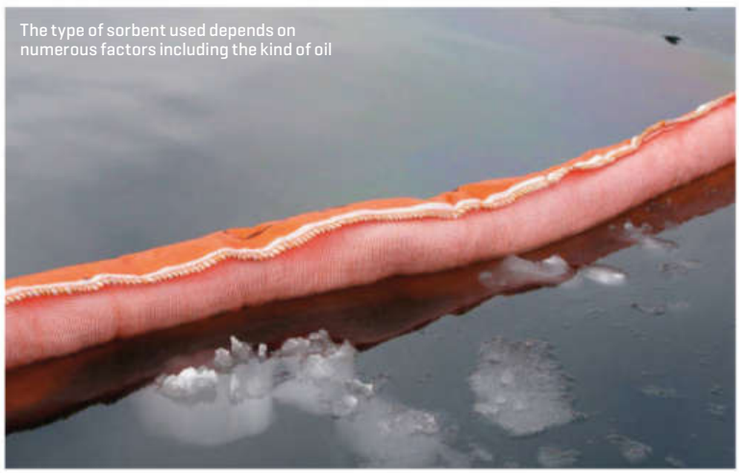

The type of sorbent used depends on numerous factors including the kind of oil

IMAGE © MARK LEEN

SYNTHETIC SORBENTS ARE SIMILAR TO PLASTIC AND CAN ABSORB UP TO A STAGGERING 70 TIMES THEIR WEIGHT IN OIL

The easiest way to clean up contaminant from the ocean is with the use of a sorbent – an insoluble material designed to absorb a pollutant or hold a thin film of the offending liquid on its multiple layers. When used to combat oil spills, sorbents must be both oleophilic (oil-attracting) and hydrophobic (water-repelling).

Sorbents are most useful for cleaning up small regions of contaminated water where skimmers cannot reach, and for removing the final dregs of oil when all other methods have been utilised.

Sorbents can be natural organic, inorganic or synthetic. Peat moss, sawdust, feathers and pretty much anything that contains natural carbon can be used as an organic sorbent. These materials are able to absorb up to 15 times their weight in oil.

Natural inorganic sorbents can absorb up to 20 times their weight in oil, and include clay, perlite, vermiculite, glass wool, sand and even volcanic ash.

Synthetic sorbents, meanwhile, are similar to plastics and can absorb up to a staggering 70 times their weight in oil. This is achieved by the way they absorb liquids into their solid structure and swell many times their original size.

The type of sorbent used depends on the circumstances of the specific spill and the kind of oil involved – for instance, gasoline, diesel fuel and benzene – and must take into account sorbent factors like rate of absorption, oil retention and the ease of application.

About 80% of Mediterranean sewage is untreated

This sewage often brings about eutrophication, which is a cause of dead zones in the sea

6 DISPERSANTS FROM THE SKY

Recovery from above is an oft-used technique to clean up the seas

ABOVE Dispersants work by breaking up the surface slick into smaller droplets

What happens when an oil spill occurs out at sea and weather conditions prevent the more common response techniques from being deployed? The most effective way to contain and limit the damage of the contaminant in these circumstances is by releasing a dispersant into the ocean from the air.

Oil naturally disperses as waves break up the surface slick into droplets that then become suspended beneath, in what's called the water column (an imaginary column of water from the surface of the ocean to its underlying sediment). A dispersant contains surfactants, or solent compounds, and works to accelerate this natural process by breaking down the oil into small droplets.

'CHEMICAL BREAK-UP' AT SEA MUST BE MONITORED CLOSELY AND STOPPED WHEN CONDITIONS ALLOW

Unfortunately, dispersants sprayed in a recovery operation involving very thick, viscous oils have limited effect because they tend to run off the oil into the water before the solvent can penetrate. Even oils that can be dispersed often become resistant after a few hours or days as the weathering process makes the contaminant more gelatinous and sticky.

Any 'chemical break-up' at sea must be monitored closely and continually, and stopped as soon as conditions allow. This way responders are able to limit the adverse effects of releasing too much dispersant into the ocean, such as the tainting of fish or potential damage to nearby coral reefs.

5 SHORELINE RECOVERY

If oil reaches terra firma, a swift and systematic response is essential

One of the worst repercussions of an ocean oil spill is the damage inflicted on nearby shorelines. Left untreated, oil sticks to rocks and sea walls, and can sink into sediments, making large swathes of coast uninhabitable to marine life. One of the worst oil slick shoreline disasters was in 2002 when the Prestige oil tanker sank off the Spanish coast, destroying the local fishing industry and polluting more than 100 beaches in France and Spain.

Any response to shoreline oil pollution must therefore be swift and systematic. Pooled contamination is first cleaned using a combination of vacuum trucks, pumps and skimmers, while thick, emulsified oil and sediment is removed using tractors and mechanical lifters. Often man power is the easiest way of cleaning sensitive shores and areas vehicles can't reach.

High volumes of low-pressure water is then flushed into stranded or buried oil to wash it from the shoreline. A similar method known as 'surf washing' uses the natural cleaning action of coastal waves to release the oil from the sediment. The final stages of a shoreline recovery involves the use of machinery to wash down hard surfaces with hot or cold water. Pebbles and cobbles are thrown into the revolving drums of concrete mixers for washing. Where rocky shorelines restrict the access of dedicated machinery, washing by hand may be the only option. Certain circumstances may call for bioremediation to accelerate the natural degradation of oil into simple compounds, but this invasive treatment is often a last resort limited to cleaning up industrial areas.

POOLED CONTAMINATION IS ORIGINALLY CLEANED USING A COMBINATION OF VACUUM TRUCKS, PUMPS AND SKIMMERS

A mix of man and machine are involved in cleaning up coastlines

4 FUNGI AND FOLLICLES

There are some novel and natural methods to cleanse polluted waters

Hair naturally absorbs oil so is the perfect material to soak up slicks

IMAGE © MATTER OF TRUST

HAIR MATS THE SIZE OF DOORMATS WERE HANDED OUT TO 7,000 VOLUNTEERS TO MOP UP 58,000 GALLONS OF OIL

In 2006, the Philippines experienced its worst-ever oil spill and tried a novel method of cleaning up the mess – using mushrooms and human hair. Thousands of inmates from Philippine prisons had their heads and chests shaved of hair, which was then combined with feathers. This created a spongy material that was used to absorb over 50,000 gallons of industrial fuel that had seeped from a sunken tanker off the central island of Guimaras.

In 2007, the technique was deployed again in the Cosco Busan spill on San Francisco Bay. Specially created, tightly woven 'hair mats' the size of doormats were handed out to 7,000 volunteers to mop up some 58,000 gallons of oil that had bled from a cargo ship, which had hit the base of the Bay Bridge. Once the giant Brillo pads had absorbed all the oil they could, oyster mushrooms were grown on the mats to suck up the oil and turn the polluted human hair into nontoxic compost within three months.

"Hair naturally absorbs oil from air and water and acts as the perfect sponge for an oil slick," says Lisa Gautier. "It acts as the perfect sponge." Gautier runs a non-profit charity called Matters of Trust that donated 1,000 hair mats to the cause. Gautier sourced the human hair from Bay Area salons, originally making the mats for the San Francisco Department of the Environment for them to absorb motor oil. How is that for resourcefulness?

ABOVE Believe it or not but within those booms are millions of hair fibres

3 CONTAINMENT DOME

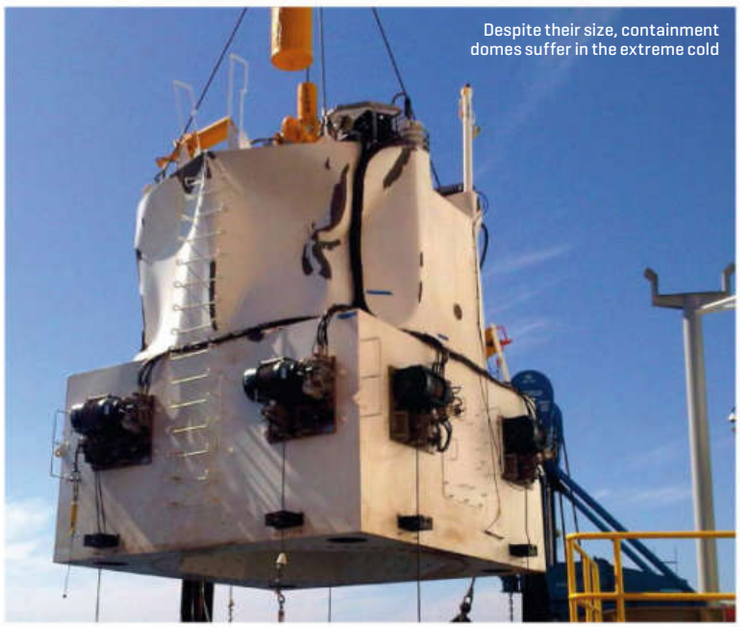
If an oil well blows, it's time to roll out the 100-ton reinforcements

A containment dome is part of a system designed to contain an underwater blowout of an oil well. It works like a giant vacuum, sucking up the pollutants that are expelled from a blowout and transporting them to a containment system stationed on a ship moored directly above the dispersion.

A containment dome was used following the devastating 2010 Gulf of Mexico explosion on the Deepwater Horizon oil rig that led to a firestorm in which 11 people were killed. A 100-ton steel and concrete dome was considered the best short-term solution to halt the flow of oil into the ocean that would go on for weeks.

Sadly, on that occasion, the dome was deemed a failure after ice-like crystals called 'hydrates' formed on the inside of the dome at a depth of 5,000ft. Hydrates occur when gas and water mix at the seabed where there is low temperature and high pressure. The Deepwater recovery team tried to pump water down a hose into the dome to keep its temperature high enough to prevent the crystallisation, but their attempts were unsuccessful – the lighter-than-water formations clogged up the dome and obstructed the passage of oil, which also had the effect of making the dome too buoyant to form a water-tight seal on the seabed. The spill continued for almost three months before the well was finally capped.

A CONTAINMENT DOME WAS USED FOLLOWING THE DEVASTATING 2010 GULF OF MEXICO EXPLOSION ON THE DEEPWATER OIL RIG



Despite their size, containment domes suffer in the extreme cold

IMAGE © KUOW FOIA

RANDOM MATTER

Infected shellfish results in numerous deaths

It's estimated that this is the cause of 50,000 to 100,000 people dying each year

From PC to the seas: Boyan Slat's clean-up vision is becoming reality

IMAGE © THE OCEAN CLEANUP FOUNDATION

2 PLASTIC ARRAY

A 19-year-old Dutch lad's school project could prove the solution to the world's ocean garbage patches

ABOVE Boyan Slat could have gone some way to clearing up the world's polluted oceans. Not bad for a Dutch lad who's not long out of school

Cleaning the oceans of man-made waste was traditionally thought to be impossible because of the vastness of the areas in which plastic is concentrated. Indeed, it's estimated that any effort to remove the rubbish using vessels and nets would take about 79,000 years and tens of billions of dollars to achieve, not to mention cause untold damage to marine life.

That was before 19-year-old Dutch entrepreneur Boyan Slat appeared on the scene. Slat's school project analysed the size and amount of plastic particles in the ocean's garbage patches. His final paper went on to win several prizes and Slat continued to develop his concept during the summer of 2012, before revealing it several months later at a TEDx event.

Slat's system involves an array of floating barriers, which first catch and concentrate the plastic debris using the natural movement of ocean currents, while allowing current flows and sea life to pass underneath these booms unharmed. The scalable array of floating barriers, which are attached to the seabed, is designed for large-magnitude deployment, covering millions of square kilometres while remaining stationary.

In February 2013, Slat dropped out of school to start The Ocean Cleanup Foundation, a non-profit organisation that aimed to develop his proposed technologies. A subsequent crowd-funding campaign raised over $2 million, enabling the organisation to start the pilot phase, which will be deployed next year. The first barrier will be placed off Japanese shores. If the pilot system works, more of the floats will be placed in the Pacific.

It is thought the system will prove to be 7,900 times faster and 33 times cheaper than conventional clean-up methods – some feat for a man who has only just turned 21.

IT IS THOUGHT THE SYSTEM WILL BE 7,900 TIMES FASTER THAN CONVENTIONAL METHODS

1 LITTER PREVENTION

The best way to cure the problem is to stop it in the first place

IT HAS BEEN CALCULATED THAT AROUND 2.5% OF THE WORLD'S PLASTIC ENDS UP IN THE SEA

Researchers estimate that about 4 million to 12 million metric tons of plastic was washed offshore in 2010 alone – or about 1.5% to 4.5% of global plastic production, which is enough to cover every single foot of coastline on the planet. And every decade, global production of plastics doubles.

"It's as if you were vacuuming your living room and I'm standing at the doorway with a bag of dust and a fan," says Chris Wilcox. "You can constantly keep vacuuming, but you could never catch up." Wilcox is an ecologist at CSIRO, Australia's national science agency, which recently released a study concluding that only 20% of ocean plastic comes from marine sources, such as discarded fishing equipment or cargo ship accidents. The rest is the result of beach litter washed out to sea or carried downstream in rivers. About half of that litter is plastic bottles. The majority of the rest is packaging.

Most of the rubbish collects in five patches located in the Atlantic, Pacific and Indian Oceans. One of these areas lies a few hundred miles off the coast of North America and the coast of Japan, and has become known as the Great Pacific Garbage Patch – a sea of jetsam, chemical sludge and assorted debris, continuously mixed by winds and waves and dispersed throughout the top section of the water column over vast distances.

Scientists estimate that it contains in the region of 480,000 pieces of plastic per square kilometre. Charles Moore, who first mapped the area, calculates that 2.5% of the world's plastic ends up in the sea and that the Great Garbage Patch contains 200 million tons of the stuff.

Some of these plastics find their way into the digestive systems of marine birds and animals, while others absorb organic pollutants from the sea water that can cause hormone disruption if they enter into the food chain. And the impact on ocean life is only getting worse. "The essence of the solution is to provide incentives for people not to throw this stuff away in the first place," says Wilcox. But in a modern-day throwaway consumer culture, the challenge is great indeed.

The world's beaches and oceans are drowning in plastic that won't decompose for up to 1,000 years

ABOVE Sadly, this is a common coastal sight in countries all around the world

Tim Hardwick
Science writer
+ Tim Hardwick is a freelance writer whose interests include science, technology and evolutionary biology. ***@markustimwick***

RANDOM MATTER

The Earth's crust also has a tide

Moved by the same gravitational forces as the ocean's tides, terrestrial tides can reach an amplitude of 55cm

The power of the tides

They contain a consistent mass of potential energy, but how can we efficiently tap into this vast resource?

WORDS BY **David Boddington**

We are running low on fuel. The near-empty indicator light is blinking away, but there isn't another service station on this road to quench our thirst for fossil fuels. Globally, we consume the equivalent of more than 11 billion tons of oil in fossil fuels. At the current rate of consumption, all existing reserves of oil, gas and coal will be gone by 2088.

So it is imperative that as the global population ticks ever upwards, we find better ways to take advantage of natural, renewable energy sources. In Europe alone, wind power already covers more than 7% of the electricity demand, and by 2020, 230 GW of wind power capacity will be available in the EU. Solar power, too, has been widely adopted, with 178 GW of power developed globally in 2014. But that is still a tiny proportion of the estimated 17.7 TW the world needs every year.

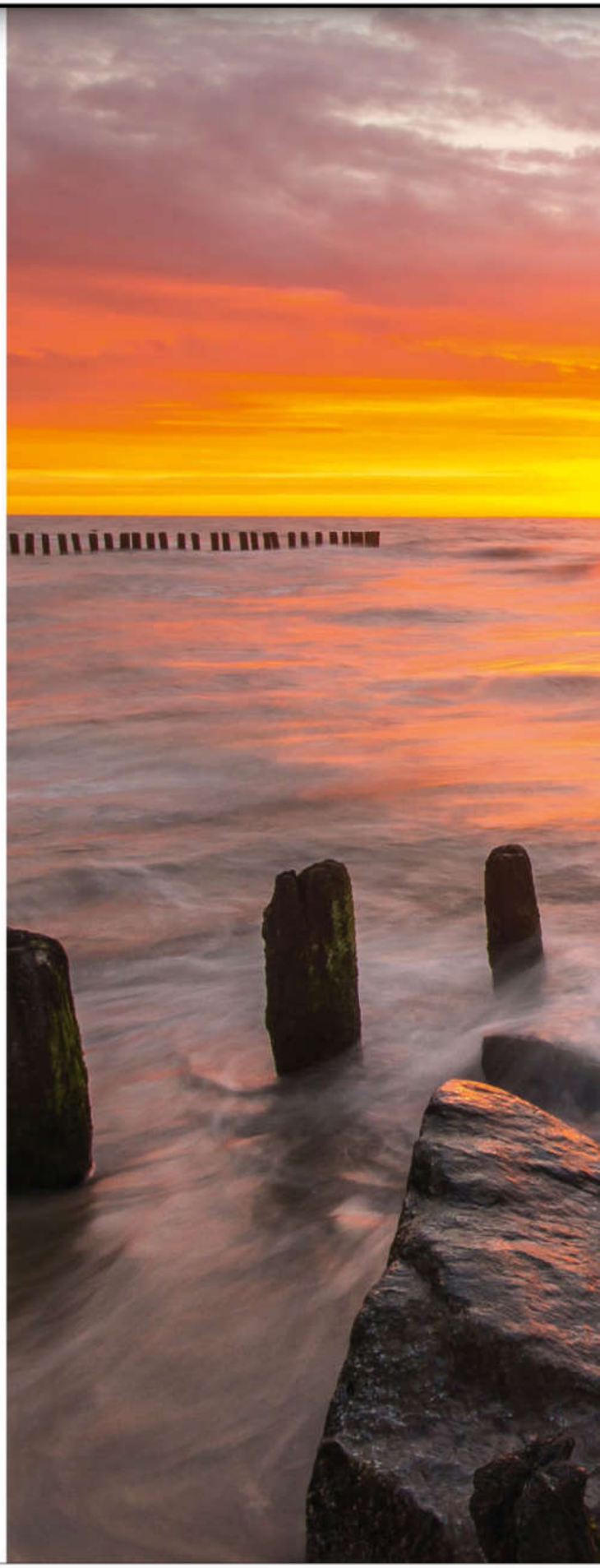
Clearly, wind and solar power generation rely on significant variables, especially in a climate like Britain's. Conventional hydroelectric power stations and run-of-river schemes now account for more than 1.65 GW of the UK's power generation – 1.8% of total generation capacity – but there's more raw energy around our shores that can be reliably harnessed. And it doesn't get much more reliable than gravity.

A RELENTLESS RESOURCE

Our tides are governed by the combined gravitational effects of the Moon and Sun, and the Earth's own rotation. The alignment of these celestial bodies causes the Earth's entire body of water to be pulled away from the planet's surface towards them, which is seen as a rising or lowering of the sea level.

This happens in different ways around the world, but in a highly predictable fashion at each location. The potential energy contained within such a volume of water is enormous and, with the right technology, can be harnessed and converted into a usable form. Harnessing this power is

THE POTENTIAL ENERGY CONTAINED WITHIN THE OCEANS IS HUGE... WITH THE RIGHT TECHNOLOGY, IT CAN BE CONVERTED INTO A USABLE FORM



The first electric wind turbine was built in 1888

It was capable of generating 12 kW of power with its 144 rotor blades made of cedar wood

RANDOM MATTER

Hydro power is huge

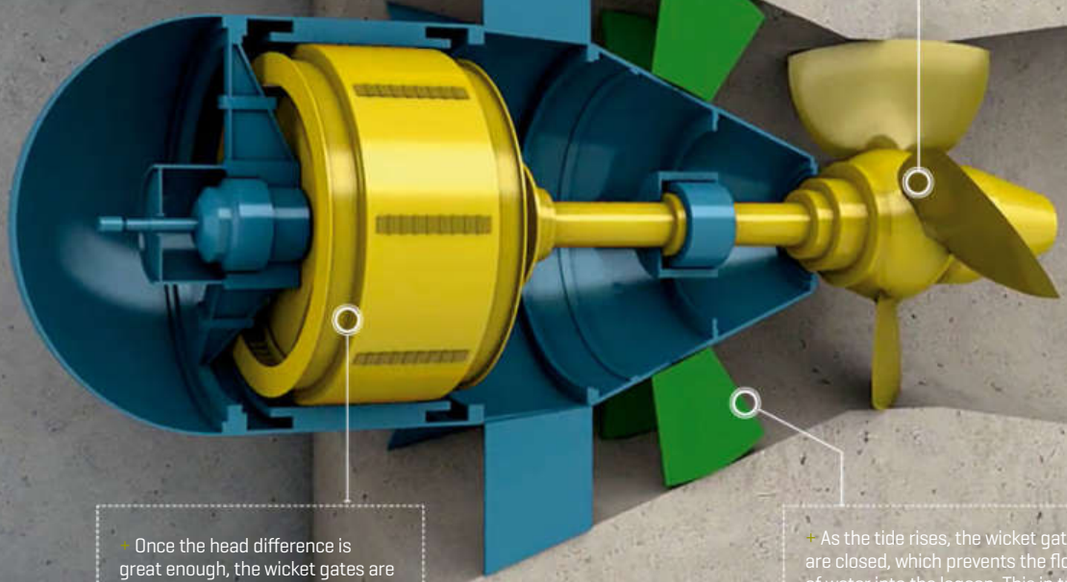
The Three Gorges Dam power station in China is the world's largest with a capacity of 22.5 GW

HARNESSING THE POWER

Turbines are at the heart of maximising the potential energy of Swansea Bay

+ The Tidal Lagoon power station at Swansea Bay will have a 550m long turbine wall, which will contain up to 26 Kaplan bulb turbines, each one 6m in diameter and 18m in length. Encased in concrete housings, they will remain constantly submerged except for maintenance.

+ The Swansea project will also pioneer the use of variable speed regulation technology for the runners, meaning they are effective triple regulated, increasing efficiency and making each one capable of generating up to 16 MW per hour.



+ Bulb turbines are usually double regulated, so in addition to the wicket gates controlling flow, the pitch of the propeller or 'runner' can be also be adjusted to maximise power generation under different tidal conditions.

+ Once the head difference is great enough, the wicket gates are opened, and the water is allowed to flow through, which causes the turbine blades to spin, until water level equilibrium is restored.

+ As the tide rises, the wicket gates are closed, which prevents the flow of water into the lagoon. This in turn creates the variance in water level between the two sides of the wall.

ABOVE An artist's image of how Swansea's Tidal Lagoon will look

however, nothing new. 'Tide mills' were widely used the in the middle ages, and may have been used in London as far back as 100 AD. They were created by constructing a dam across a tidal inlet or estuary, with a one-way gate then allowing the tide to flow in, but retaining the water behind the dam once the tide had retreated. This water could then be released in a controlled manner to turn a waterwheel, which in turn would drive mechanisms to grind grain.

Substitute the wooden water wheel for a metal turbine, and in essence you have one of the four modern types of tidal power generation – the Tidal Barrage. But there are three other methods of power generation that are still being explored.

Tidal Stream Generators can be thought of as underwater wind turbines, which can use the kinetic energy of the flowing tide in both directions. Quirks of local geography, such as narrow straits, can create a very fast-flowing current, meaning a lot of energy can be captured by the turbines. Some designs can even be incorporated into existing structures like bridges, making them all but invisible.

Another as yet untested method is Dynamic Tidal Power generation. It's proposed that in areas of shallow coastal seas, 30-50km-long T-shaped dams are constructed, reaching out from the coast without actually enclosing an area. By introducing these, a tidal phase difference is created between the two sides of the dam, and thus an imbalance in local sea level known as the 'head difference'. Bi-directional turbines in the dam would then generate the power as the water flowed down through.

Finally, Tidal Lagoons offer an interesting and scalable alternative. These work in a similar way to Tidal Barrages, but crucially do not rely on any existing geography, as they are entirely man made. A large circular walled structure creates a new artificial reservoir at sea, and turbines embedded in the wall harness the potential of kinetic energy conversion as the tide ebbs and flows. They can also be built in double or triple ring format, which flattens out power generation spikes.

To date there are fewer than 10 operational tidal power stations around the world, but this number is growing. The first constructed, and one of the largest, was built across the estuary of

HOW TIDES ARE GOVERNED

Many variables come into play...

+ Tides are largely caused by the gravitational pull exerted by the Sun and the Moon. Timing and height vary from one location to another due to the relative positions of those bodies, the structure of the coastline and the shape of the local ocean floor. Some coastlines have a diurnal tide, or one high and one low per day, while others experience a semi-diurnal tide, meaning two high and low tides each day. This makes such locales especially promising for tidal power generation, as is the case in Swansea Bay.

The maximum high and low tide also varies in a predictable manner at any given location. Twice each lunar month, when the Moon is new or full and it is aligned with the Sun and Earth - a state known as syzygy - the tidal range is at its maximum. This is referred to as the 'spring tide'. At the other end of the spectrum, also twice a month, when the Moon is waxing at first quarter and waning at third quarter, the tidal range is at its lowest and is called the 'neap tide'.

The largest tidal range in the world can be found at the Bay of Fundy in Canada. Here, the difference between high and low tide can be as great as 16.3m, and it is harnessed by North America's only tidal power station on the Annapolis River. The UK is not far behind, as the Severn Estuary regularly sees a tidal range of 15m.

the Rance River in Brittany and opened in 1966. It's a Tidal Barrage station capable of delivering 240 MW at peak, thanks to its 24 turbines spanning 750m, and supplies France with 0.12% of her electricity requirements.

Other tidal power generation sites are found in South Korea, China, Canada, Russia and in Northern Ireland, the latter of these being the Strangford Lough SeaGen station. Weighing in at 300 tons, the world's first commercial Tidal Stream generator produces 1.2 MW of power for more than 18hrs each day. Poetically, it's located close to the site of one of the oldest tide mills ever found, at Nendrum Monastery, dating from 619 AD.

TIDAL ON THE HORIZON

Many more tidal stations are either in development or already under construction. Granted planning permission from the Department for Energy and Climate Change in June 2015, the Tidal Lagoon Swansea Bay is thinking big. The first station in the world to adopt the Lagoon technology, the development at Swansea Bay will benefit from an average tidal range of 8.5m during spring tides and 14hrs of reliable power generation each day.

Its capacity will be a staggering 320 MW and this will, in turn, contribute towards the national carbon emission reduction targets by more than 236,000 tons of CO_2 each year. It's lagoon wall will be between 5 and 20m high, 9.5km in length, and will enclose an area of 11.5km^2.

The developers of the station are aiming to build a fleet of six located around the United Kingdom, which combined would generate 15.9 GW of power, supplying approximately 8% of the UK's demand. This is the equivalent of 4,416 offshore wind turbines, or 10 nuclear-pressurised water reactors.

The opportunity presented by harnessing the unrelenting power of the tides is enormous, and as we struggle around the world to conserve fossil fuel resources, reduce carbon emissions, and strive to leave a cleaner planet for generations to come, investment today in tidal power generation is a great step in the right direction. As we build, we will learn. Power generated at each site will increase as the technology improves, and construction and manufacturing costs will come down as key developments are standardised.

Ultimately, in a world where so many things are impossible to predict, we could do a lot worse than bet our future energy harvesting on the certainty of the ebb and flow of the ocean tides. DB

David Boddington
Science writer
+ David is a biology graduate who's regularly worked for the Discovery and History channels, written for numerous science publications, and is now part of The Yogscast. *@bodbod*

RANDOM MATTER

Sea levels are rising by 2.75mm annually

If Greenland fully melted, it's thought that global sea levels would rise by 7 metres and Antarctica by more than 60 metres

SAVING OUR SEAS FROM HOME

Marine pollution takes many forms and comes from many sources, but there are actions each and every one of us can take to help protect our oceans

WORDS BY **David Boddington**

It is easy to think of ocean pollution as something only related to heavy industry or large-scale disasters. The reality however, is far closer to home, and on a scarcely believable scale.

Almost every area of our lives has an impact upon the health of our oceans. From nipping out to buy ingredients for supper to washing the dishes, every step of the way we are making decisions and taking actions that can add to the mounting tide of marine pollution. However, there are small changes we can all make at home that can make a huge difference.

SURPRISING SOURCES

The Deepwater Horizon oil spill was so extensive, it's still visible from space today, more than five years on. It's estimated that over 4.9-million barrels of oil were discharged into the ocean before the leak was capped, causing widespread ecological devastation. But even something as terrifyingly large as that is only the tip of the iceberg. Although generating far fewer column inches, it's thought that almost half of all the oil polluting the oceans actually comes from everyday sources, like the cooking fats we pour down the sink or the road film from the one-billion motor vehicles in use around the world. All these seemingly small sources add up, and gravity sees to it that everything ends up flowing into the sea.

Other toxins leaking from our daily lives can wreak further havoc at sea. Phosphates are used widely by land, forming a large part of chemical fertilisers, washing detergents and soaps, and also feature heavily in the unavoidable outflow of human and animal waste. Even with sophisticated modern waste water treatment, these seemingly helpful chemicals still find their way into the oceans. Here, their life-giving, fertilising properties cause more harm than good by instigating a process known as

In America, 40% of rivers are deemed unsafe to swim in

That figure's down to pollution from human sewage and people directly dumping pollutants

FROM BUYING FOOD TO WASHING DISHES, WE'RE ADDING TO THE TIDE OF MARINE POLLUTION

MARINE SPECIES UNDER THREAT

Five aquatic animals that are suffering because of human pollution

1 BLUE WHALE

+ There are only between 10,000 and 25,000 blue whales left in the oceans. We run the risk of this number reducing further, as their main source of food, krill, are themselves under threat thanks to rising ocean temperatures and salinity levels thanks to global warming.

2 LEATHERBACK TURTLE

+ Numbers of leatherback turtles have been dropping for the last 20 years due to a variety of factors including ocean debris. As they feed primarily on jellyfish, they are especially prone to swallowing plastic bags by mistake.

3 GALAPAGOS PENGUIN

+ There are only 1,000 breeding pairs of Galapagos penguins alive today. During the 1980s they declined sharply, with El Niño causing mortalities of up to 77% because of reduction in prey. Increased oil pollution has also had an impact.

4 FLORIDA MANATEE

+ Between 1995 and 2005, 38% of all Florida manatee deaths were caused by humans, including the release of toxic pesticides into their local environment. There are thought to be only around 2,500 mature adults left. This is likely to decline by 20% over the next two generations.

5 POLAR BEAR

As global temperatures rise, the sea ice on which the polar bear hunts reduces every year. Increased Arctic oil drilling also poses a threat, as coming into contact with oil can destroy the integrity of their fur. As they are at the top of the food chain, bears also accumulate high levels of potentially fatal toxins like polychlorinated biphenyl and chlorinated pesticides.

RANDOM MATTER

The Arctic's the warmest it has been for 40,000 years

Researchers predict that the Arctic will experience an entirely ice-free summer season by 2037

IMAGES © THINKSTOCK, LUNCH/WIKIMEDIA

ABOVE The 2 Minute Beach Clean is a project designed to make common images like this a thing of the past

RIGHT Seals and sea lions are often victims of fishermen discarding nets

eutrophication. As nutrient levels rise in the water, simple plants and algae 'bloom' and then decay, which in turn decreases the amount of oxygen available to other organisms, severely reducing animal populations. Long term, this can lead to the collapse of local ecosystems and food webs.

Atmospheric pollution can also have a significant long-term impact on our oceans. It's estimated that between 30% and 40% of carbon dioxide released into the atmosphere dissolves into the water cycle, increasing acidity. This can have serious implications for organisms that rely on calcium carbonate structures, as they are likely to dissolve, impacting corals and the shell formation of other animals.

THE PLASTIC PROBLEM

Some other pollutants, once they make it to the sea, can drift around the world for years. Around 80% of such debris is made up of plastic. Most plastics take several hundred years to decompose, meaning that once they make it into the water cycle, they need to be manually removed. Some estimates suggest the mass currently circulating the oceans could be as great as 100-million tons.

A significant amount of plastic derives from shipping containers lost at sea. The World Shipping Council estimates that between 2011 and 2013 around 2,683 containers were lost, containing masses of plastic goods. One container lost off the Cornish coast contained over 4.7-million pieces of Lego, which still wash up on beaches around the world today. But again, it's the regular household rubbish we discard that makes up the bulk of plastics pollution.

Plenty of plastics are disposed of by holiday makers at the beach, but even household plastic waste that goes to landfill can end up in the water system following mechanical breakdown into smaller pieces. Many animals actually consume plastics by mistake, thinking them sources of food. These can cause sickness, distress and often death.

ABOVE Plastic pollution, both large and small, results in a distressing death for both marine life and birds

Some of this wild plastic accumulates in ocean gyres – very large systems of rotating currents – and these debris build-ups can become massive. First observed in 1972, the so-called 'North Atlantic Garbage Patch' is within once such gyre, and is thought to be hundreds of kilometres in diameter, and to contain more than 200,000 pieces of debris per km^2. However, these are not static accretions. They can move by up to 1,600km north and south and, in doing so, debris can spin out and has been found in places as remote as the High Arctic.

STEMMING THE TIDE

With so many sources of marine pollution on such a baffling scale, it can be difficult to see how individuals can make a real difference. But we can, by tackling the problem before it even

It takes 1,000 years for plastic bags to decompose

Normal microbial activity isn't enough to break down the complex polymer chains that make up modern plastics

Q&A DR SIMON BOXALL

National Oceanography Centre at the University of Southampton

How can we tackle the problem of ocean pollution from a treatment perspective?
You can't. Organic material (oil, sewage) does break down and letting nature take its course is the best option. Plastics are here for the long term. It would be impossible to comb them for all of the microscopic plastic particles. Let's not increase the already alarming levels anymore.

How much household plastic waste is dumped each year?
As a nation we're getting better at recycling and being cautious about our plastic waste. Recent work by the University of Miami, who have been monitoring plastic levels off the coast of Florida, shows that while our use of plastics has increased year on year, the levels in this region have levelled out. It's good news - we're better than we were.

What can people do to help when they are visiting the coast?
Always clear up your rubbish, at the beach and in the forest (water works with gravity and it all ends up in the ocean eventually).

How will a change in buying habits help?
Is the fish you're eating sustainable and caught in a sustainable way? The species under threat vary from year to year, but it's not hard to find the best things to eat in terms of the environment. A UN report at the start of the millennium estimated that we could provide the world's protein needs from the ocean, if managed carefully.

Deposit yours and, if needed, other people's beach rubbish into the bin. Or, ideally, into a recycling bin

A UN REPORT HAS ESTIMATED THAT WE COULD PROVIDE THE WORLD'S PROTEIN NEEDS FROM THE OCEAN, IF MANAGED CAREFULLY

begins. "It is always better to prevent litter at source, rather than trying to clean up the oceans afterwards," says Dr Laura C. Foster of the Marine Conservation Society. "One eminent professor has likened us currently trying to clean up the litter in the oceans as having a bath with the taps running on full, and trying to bail it out using a teaspoon. We need to stem the flow of litter." And this doesn't just stop with litter, as it can be applied to every area of marine pollution.

Simply by making short journeys on foot or by bike instead of jumping in the car will help not only reduce the oil seepage from our roads, but also reduce the carbon dioxide emissions that are contributing to the acidification of the seas. Just by making choices like this, we can all make a difference to the global warming, ocean life and our wallets.

We can also help reduce the enormous quantities of plastic that end up caught in gyres or harming wildlife around the world just by changing the way we shop. Opting for foodstuffs with biodegradable packaging, using our own bags instead of those at the supermarket, not buying hygiene products containing micro-beads – these things all add up. And then, of course, when we do have to use plastic, making sure we separate from other waste and recycle.

THE RIGHT RETAIL OPTION

Purchasing choices also matter when it comes to the product itself. Buying phosphate-free cleaning products will help combat problems such as eutrophication, while making sustainable seafood choices ensure long-term conservation of entire ecosystems. "Small artisan fishing boats and some types of line fishing cause no impact on the fish stocks of the ocean," says Dr Simon Boxall of the National Oceanography Centre at the University of Southampton. "The problems are the vast factory trawlers and ships with nets over a mile wide that scrape the seabed clear. It takes many years for the environment to recover from such methods and so how your fish fingers were caught is as important as what is in them."

And when prevention fails, there are still things you can do to help. Projects such as the 2 Minute Beach Clean, which can be found at www.beachclean.net, and encourages everyone visiting a beach to spend precisely two minutes of their time before returning home to collect any waste plastic they can find and add it to their existing recycling. It's these small individual efforts and changes that, on a global scale, can add up and quite literally change the world. DS

David Boddington
Science writer
+ David is a biology graduate who's worked for Discovery and The History Channel and is now part of The Yogscast. *@bodbod*

RANDOM MATTER

Global coral reefs cover an area the size of Italy

That estimate equates to an underwater mass of 284,300 square kilometres

FAKING IT!

WORDS BY **Andrew Westbrook**

The UK is the 12th largest reef nation

It has 5,500 sq km of reef (2% of the world total). It's almost all located in overseas territories

Reef systems are suffering a decline, but could manmade alternatives be the solution?

Coral reefs are incredible. Despite covering less than 1% of the planet's surface, they support at least a quarter of all marine life. Unfortunately, they're also in serious trouble, with researchers estimating that half of them have been wiped out in the last 50 years. What can be done?

One potential solution – attracting support and controversy in equal measures – is manmade reefs. From concrete blocks to old warships, these are structures placed on the seabed with the aim of mimicking a natural reef to attract marine life.

The practice isn't new, with archaeological evidence suggesting fishermen in the Mediterranean and elsewhere have been using the method to improve their hauls for thousands of years. However, with corals reefs – and, more critically, fish stocks – coming under increased pressure, recent decades have shown a dramatic increase in the implementation of artificial reefs.

JAPANESE INNOVATION

In Japan, fishermen since the 1650s have been regularly sinking large rocks to form new reefs. From the 1950s, this grew into a massive project on a national level. Concrete blocks and metal towers were

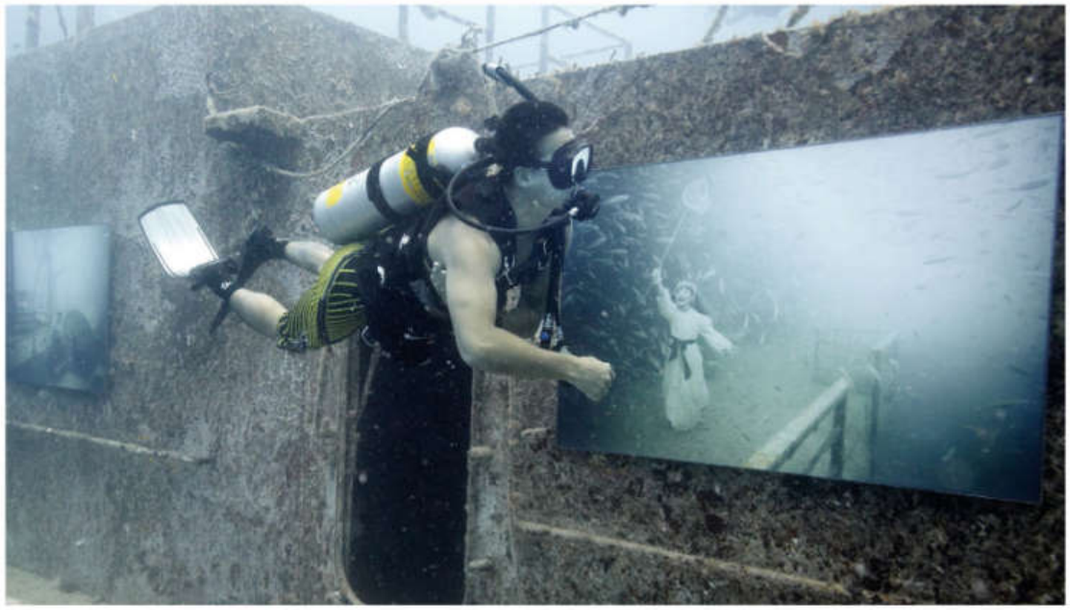
El Nino (1998) was devastating for coral reefs

It caused the loss of about 90% of the corals in parts of the Indian Ocean

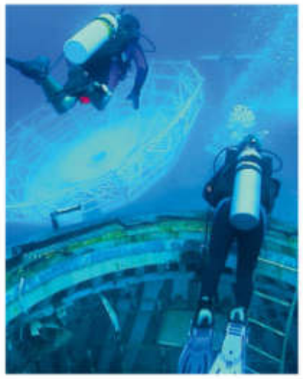
HOW NATURAL REEFS ARE FORMED

Coral, plankton, algae and time are key to reef development

+ Coral reefs start with a symbiotic relationship between miniscule algae and corals, which are living organisms related to sea anemones and jellyfish. This double-act works together, the algae within the coral. The corals live in colonies of individuals, or polyps, which feed by catching plankton with their tentacles. As they do this, they secrete calcium carbonate, the hard material that gradually forms the base of the reef and provides protection for the polyps. The algae, in the meantime, use the safe environs of the coral to trap sunlight. This energy is converted into sugars, through photosynthesis, which is then shared with the coral. Growing at a rate of 0.3–10cm per year, depending on the species of coral and environmental conditions, it can take thousands of years for a reef to form.



IMAGES @ ANDREAS FRANKE/FLORIDA KEYS NEWS BUREAU; HAIG JACOBS; SCOTT BROWN



ABOVE A diver examines art created by Andreas Franke along the deck of an artificial reef in the Florida Keys National Marine Sanctuary

FAR LEFT The USNS General Hoyt Vandenberg, shortly before becoming the second largest artificial reef in the world...

LEFT Divers observe a satellite dish of the sunken vessel

ABOVE The General Hoyt Vandenberg is sunk seven miles off Florida in 2009. It's now an artificial reef and has become a habitat for 113 species of fish

IMAGE @ ANDY NEWMAN

IN FLORIDA, THERE ARE 3,000 ARTIFICIAL REEFS... PROVIDING SITES FOR FISHING AND SCUBA DIVING

sunk to serve as propagation grounds for fish, shellfish and seaweed, the aim being to boost coastal fishing. The scale of the project was staggering. In just the decade from 1976, for example, the government spent US$4.2 billion on the scheme, deploying 6,443 artificial reefs. The project is ongoing, with the reefs now covering some 20 million cubic metres.

Fears remain, however, that the reefs don't increase overall fish stocks, but merely lure existing stocks closer together, making them easier to catch. "This is referred to as the 'aggregation/production' issue and is hotly argued," explains Dr Tom Wilding, who leads the Scottish Association for Marine Science research team at the Loch Linnhe Artificial Reef.

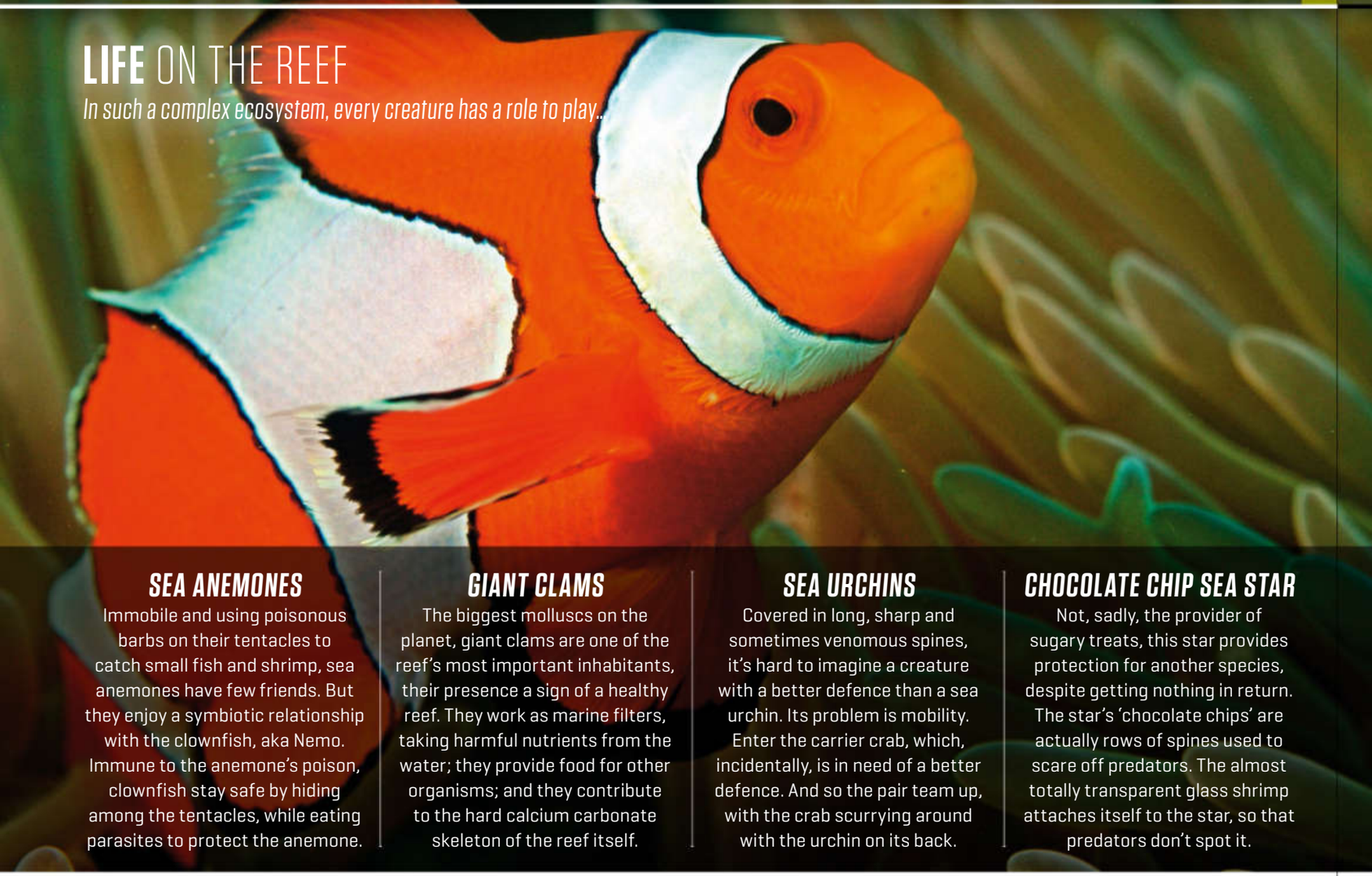
"Artificial reefs have been used extensively to 'benefit' wild fisheries," he continues. "But no-one really knows whether they actually enhance populations. The reality is that, for some species, there will be genuine production. At other times and structures, the reefs will merely aggregate existing biomass. The problem with the latter is that artificial reefs promote over-fishing."

DESIGNED FOR FISHING

Despite that argument being far from settled, artificial reefs have continued to grow rapidly in numbers, most notably in the United States. This has been most prominent in the Gulf of Mexico states, such as Louisiana and Florida. In Florida alone, there are now almost 3,000 artificial reefs. The emphasis has been vastly different to Japan, concentrating more on providing alternative sites for sports fishing and scuba diving. The methodology has also been different, relying less on specially made reef technology and more on recycling waste materials,

LIFE ON THE REEF

In such a complex ecosystem, every creature has a role to play...



SEA ANEMONES

Immobile and using poisonous barbs on their tentacles to catch small fish and shrimp, sea anemones have few friends. But they enjoy a symbiotic relationship with the clownfish, aka Nemo. Immune to the anemone's poison, clownfish stay safe by hiding among the tentacles, while eating parasites to protect the anemone.

GIANT CLAMS

The biggest molluscs on the planet, giant clams are one of the reef's most important inhabitants, their presence a sign of a healthy reef. They work as marine filters, taking harmful nutrients from the water; they provide food for other organisms; and they contribute to the hard calcium carbonate skeleton of the reef itself.

SEA URCHINS

Covered in long, sharp and sometimes venomous spines, it's hard to imagine a creature with a better defence than a sea urchin. Its problem is mobility. Enter the carrier crab, which, incidentally, is in need of a better defence. And so the pair team up, with the crab scurrying around with the urchin on its back.

CHOCOLATE CHIP SEA STAR

Not, sadly, the provider of sugary treats, this star provides protection for another species, despite getting nothing in return. The star's 'chocolate chips' are actually rows of spines used to scare off predators. The almost totally transparent glass shrimp attaches itself to the star, so that predators don't spot it.

whether that be oil rigs, ships, trains, cars, tyres and even toilets.

Not surprisingly, an early free-for-all, when saved disposal costs and boosted tourism incomes appeared the primary aims, meant not everyone was convinced.

"I view the light-touch regulation of 'reef-creation' in the Gulf of Mexico as bad practice," says Dr Wilding. "The Gulf reefs are typically small (few tons), are constructed using materials of convenience and vulnerable to being moved around during hurricanes. There has been very little research conducted on their efficacy, and the fear is they're being used as an excuse to 'dump' materials that would otherwise incur a cost."

The situation in the Gulf is improving, with a shift towards larger structures, plus stricter controls on removing potentially harmful chemicals, such as copper wiring and fuel. But tourism dollars remain the inspiration. Indeed, a recent Florida University estimated that every dollar spent on artificial reefs was worth $138 to the local economy.

AMERICAN INFLUENCE

One undoubted result of the American approach was an impact on the policy towards artificial reefs in Europe, where far fewer exist. Indeed, the scuttling of HMS Scylla off Cornwall, in 2004, made it Europe's first artificial wreckdiving site, while almost all artificial reefs tend to be installed primarily for the purpose of scientific research.

"The hey-day of artificial reef construction using materials of convenience was mostly 1960–1980," explains Dr Wilding. "The 'bad news' stories from the US led to European law making reef construction virtually impossible. The deployment of the Loch Linnhe Artificial Reef and HMS Scylla required a considerable

THE CORAL HOLOBIONT

+ It's best to consider reef decline in terms of the coral holobiont. It's one of the only systems on Earth that combines animal (the coral) and plant (the photosynthetic zooxanthellae) , along with a complex and still largely unexplored mix of bacteria and archaea. This complexity is mirrored at a higher level in the reef system, forming a remarkably interactive, joined and dependent ecosystem. So, rather than asking how the parts of the system are doing individually, it's important to ask how the overall system is faring.

RANDOM MATTER

Reefs are worth an annual $375 billion to the economy

About 500 million people depend on them for food or a livelihood

TOP FIVE **MANMADE REEFS**

There's no shortage of ideas for what can be used to construct an artificial reef

1. RIGS-TO-REEFS

+ Hundreds of former oil platforms across the Gulf of Mexico have been converted into artificial reefs. Oil companies use explosives or mechanical cutting techniques to topple the entire structure or detach the top. Environmental concerns have so far prevented the practice in the North Sea.

1

2. OSBORNE REEF

+ This Florida project is the worst example of a practice, popular in several countries in the '70s and '80s, of using old tyres to create artificial reefs. About 700,000 tyres were dumped near Fort Lauderdale, in 1972, in what has since been dubbed an environmental disaster. The tyres not only failed as a reef, but would destroy natural reefs when moved by currents

2

3. UNDERWATER ART

+ Mexico's Musa Isla Mujeres opened in 2010 and, ultimately, aims to have 12 galleries with at least 1,000 artificial structures, most of which are statues. It's hoped the museum will create new habitats for marine life while also drawing visitors away from nearby natural reefs.

3

IMAGE © CATLIN SEAVIEW SURVEY

4. REDBIRD REEF

+ The US state of Delaware used 619 decommissioned New York City subway cars, or 'Redbirds', to create artificial reefs in the Atlantic. Starting in 1995, Delaware sunk all of the 15m-long cars across 14 sites. They had been stripped of toxic materials except, controversially, asbestos.

4

5. ELECTRIC REEF

+ Serbian architect Margot Krasojevic has designed a futuristic manmade reef to be placed off Indonesia to aid tsunami protection. It incorporates an electric field, the idea being to attract calcium carbonate from the water to encourage natural coral growth. The structure comprises moveable steel girders and ball structures connected to electrical cables that are attached to floating solar panels.

5

IMAGE © MARGOT KRASOJEVIC

Two million tyres sit in Florida waters

They were offloaded in the 1970s. A recent project has so far managed to recover about 62,000 of them

LEFT Artificial reefs have become a bit of a money-spinner for many tourist boards

BELOW The USS Kittiwake was sunk in the Cayman Islands in 2011. Doors were removed to make it safer for divers

IMAGES © LAWSON WOOD; STEPHEN FRINK/FLORIDA KEYS NEWS BUREAU/HO

effort." He adds, "Wrecks can provide an exciting 'playground' for divers, but have limited value in terms of replicating natural structures. They're not natural surfaces. Although they become heavily colonised, the communities they support often do not reflect natural communities.

"Reefs enhance biodiversity when they're placed in an environment where there's little hard substrata. The biodiversity supported by such structures is, from a human perspective, often attractive. As a consequence, reefs are considered to benefit 'diversity'. Whether this actually benefits biodiversity depends on how 'benefit' is defined. There's no simple answer to that one."

A better alternative, suggests Dr Wilding, is using concrete blocks, such as at Loch Linnhe. "They're more natural and host communities that are more similar. The blocks are inert and don't cause problems with movement or contamination. However, unlike 'materials of convenience', they have to be manufactured and that has a cost."

And so the debate rages on. Proponents of artificial reefs point to fish numbers and biodiversity. But large parts of the scientific community remain unconvinced. As well as questioning fish production, they point to increased fishing at artificial reefs. There's also evidence to suggest artificial reefs don't lead to less human visitors at nearby natural reefs, but often the opposite. Which returns us to the original concern, the plight of the world's natural coral reefs.

"They're losing a few per cent a year," says Dr Benjamin Neal, shallow reef team leader for XL Catlin Seaview Survey, which is creating a visual record of the world's reefs (see 'Google story', page 110). "That means there may be no more reefs in just a few decades."

Andrew Westrbook
Science writer
+ Andrew has written for numerous publications around the world. He also has a lifelong interest in penguins! *@andy_westbrook*

LOCH LINNHE
ARTIFICIAL REEF

How the Scots have got it right

+ Found on the west coast of Scotland, this research-led artificial reef is considered an example of good practice. It was constructed between 2001 and 2006 using 175,000 concrete blocks with a mass of 6,230 tons. All the materials had been tested, with results showing they were physically robust and chemically inert. The site, chosen partly due to a lack of fishing activity, was also surveyed extensively with acoustic methods before building began. The reef system comprises five groups of six individual reefs, with the concrete blocks dropped in conical piles, allowing them to immediately interact with the environment and generate complex habitats for the seabed-dwelling benthic species. Marine life has since flourished and multidisciplinary research at the site, headed by the Scottish Association for Marine Science, continues. This includes assessing levels of fish abundance, comparing productivity between artificial and natural reefs, monitoring fluid flows and measuring changes in sedimentary oxygenation.

IMAGE © SCOTTISH ASSOCIATION FOR MARINE SCIENCE

The jury remains out on artificial reefs, but Loch Linnhe is seen as an example of good practice

WRECKS PROVIDE A 'PLAYGROUND' FOR DIVERS, BUT HAVE LITTLE VALUE IN REPLACING NATURAL STRUCTURES

RANDOM MATTER

The CSCL Globe is 400m in length

That equates to four football pitches, and is as tall as the London Eye if stood on its end

ENVIRONMENTALLY FRIENDLY SHIPPING

With global warming and ocean pollution a greater problem than ever, what are the options to make ships greener?

WORDS BY **Matthew Bolton**

IMAGE © S.PLAILY/E.DAYNES/SCIENCE PHOTO LIBRARY

Shipping is already an efficient form of transport

Estimates say it's seven times more efficient for moving goods than road transport

Though shipping is one of the more efficient ways to transport goods around the world, it still contributes up to 4% of emissions – and it's thought that this could increase four-fold by 2050. There have been international regulations relating to general pollution from shipping since the 1970s, in the form of the International Convention for the Prevention of Pollution from Ships (MARPOL), but the focus on emissions is much more recent, only being implemented in 2005.

"Most environmental regulation has focused on reducing nitrogen oxides, sulphur dioxide and particle emissions. These types of emissions are hazardous to human health. Nitrogen oxides and sulphur dioxide are toxic and cause acid rain while particulate emissions cause visible smoke," explains Dr John Calleya, naval architect at the University College of London. Limiting these kinds of emissions is important, but doesn't represent the full scale of the problem. "While the control of these emissions will have a beneficial impact on air quality and acidification, carbon dioxide reductions from all sources, including ships and other freight modes, are urgently required to reduce global warming."

GO LARGE

And though financial investment is needed to develop ways to cut emissions, the benefits from doing so are economical as well as ecological. "Targeting reductions in fuel consumption has the benefit of reducing all types of emissions and can result in more profitable ship designs, which can act as an incentive for ship owners and operators to reduce emissions," adds Calleya.

One of the simplest options is to make ships carry even more cargo. Hyundai Heavy Industries has launched the world's largest container ship, named the CSCL Globe, with a 19,000 TEU (20-foot equivalent unit – a way of measuring ship loads) capacity. This sends more products across the sea at once, but it makes better use of its available space than most other ships, and uses technology to maintain optimum fuel efficiency by monitoring its speed and the sea conditions at all times. This results in a 20% reduction in

RANDOM MATTER

A ship's engine can weigh 2,300 tons

That's for a huge container ship and is greater than the entire mass of a space shuttle

HOW TO BUILD THE ULTIMATE GREEN SHIP

The technologies and materials eco ships will use

BETTER BALLAST

+ Ships collect water as ballast, then dump it when docking, releasing invasive organisms. Ballast water can either be treated to wipe out the organisms, or a ballast-free system could be used, where water flows through channels within the ship's hull.

HEAT RECOVERY

+ Hot exhaust gases from regular engine fuel use are collected and used to boil water in a steam turbine system, generating electricity that can be used to power and drive the ship. This avoids a huge amount of heat energy simply being wasted in the atmosphere.

SAILS AND SOLAR

+ In certain shipping corridors, sails could provide a huge portion of the pushing power needed to send ships across the ocean, dramatically reducing their need for other types of power generation. Some ships will also be able to get boosts from solar power.

FUEL CELLS

+ For powering the propeller, an electric motor that gets its energy from a hydrogen fuel cell would create clean power – provided the hydrogen's created in an eco-friendly way. There are already ships that use wind power to electrolyse water to generate hydrogen.

MATERIALS

+ Ships can be made lighter and so more efficient, through higher-strength steels – but to be eco-friendly, they also need to be highly recyclable and reusable. Future material developments will also help to make hydrogen fuel cells and better batteries viable.

LEFT Maersk ships use a heat-recovery system to save money and the environment

BELOW Ballast water could be treated to eradicate potentially invasive organisms

IMAGE © JOHN READER/SCIENCE PHOTO LIBRARY

fuel use per container compared to standard smaller ships. It also features further eco-friendly systems, such as a treatment system for its ballast water, eliminating potentially harmful organisms with ultraviolet light.

However, while the CSCL Globe uses its fuel more efficiently, it still uses the same low-grade heavy fuel oil as other ships, which contains high levels of chemicals such as sulphur. But there are alternatives…

FUEL RECOVERY

Crowley Maritime Corporation is a shipping company that plans to build two large container ships that run entirely on liquid natural gas (LNG), which would offer 100% reductions in sulphur oxide and particulates emissions, and a 92% reduction in nitrogen oxide. It sounds ideal, but Dr Calleya points out that there are hidden environmental costs to it. "There are also emissions in the manufacturing of the fuel, which is important when considering alternative fuels," he explains.

Right now, the best option for reducing emissions is hybrid systems, depending on the ship. "Solutions that incorporate carbon-reducing technologies are dependent on the vessel that's being used and where it's being operated," says Dr Calleya. "For example, sail-assisted propulsion makes more sense on certain routes and slower ships where wind speed can be more favourable. Large ocean-going ships may also operate in a narrow band of speeds, which makes them more suitable for technologies that work best in this manner, such as the current generation of waste heat recovery plants."

Waste heat recovery systems are already in use in huge container ships operated by Maersk Line – its Triple-E vessels have an 18,000 TEU capacity, but claim a reduction of up to 50% per container compared to the norm. The system works by capturing hot exhaust gas from the engine in a boiler, using it to create steam in a turbine, generating electricity and providing the vessel with energy from

Container ships need few crew members

Despite its size, the CSCL Globe, for example, requires only 30 crew on its voyages

Sulphur dioxide is one of the most toxic pollutants churned out from ships

IMAGE © VOLKER STEGER/SCIENCE PHOTO LIBRARY

that otherwise wasted exhaust heat. Maersk says it reduces the ship's total emissions by 9%.

DUAL-PROPELLER DESIGN.

One of the other methods used by the Triple-E vessels is an unusual two-propeller design (instead of one), with slower revolutions. This system allows the vessel to travel just two knots slower than Maersk's own smaller E-Class vessels, but requires 25% less energy than those vessels, despite carrying more cargo.

Using slightly slower speeds is actually a tactic for reducing emissions that's become widespread. "For all ships, but for container ships in particular, the speed of the ship is very important," Dr Calleya explains. "Fuel consumption is a function of at least the speed cubed. This means that a container ship travelling around 21–25 knots can enjoy a very large drop in fuel consumption of around 40% by reducing speed by a few knots."

Reductions of around 50% are possible from existing carbon-reducing technologies, and we can expect to see things like sails become more prominent when usable – though perhaps less so with regards solar power. "The role of solar power for large ships is limited because of available deck space," Dr Calleya says. "For this reason, photovoltaic solar power can typically only generate around 2% of a large ship's energy needs." With photovoltaic cells expensive, this won't be a cost-effective way to reduce emissions.

The problem with hitting 50% reductions, though, is that it's not enough. "If we accepted a two degrees increase in climate between 2012 and 2050, the CO_2 emissions of an individual ship would have to be up to 25% of what they were in 2012," says Dr Calleya.

We'll need to look at using current hybrid technologies, but also look at better ways to store energy for ships in the future, such as hydrogen (if we can produce it in an environmentally friendly way). But making it work won't be just about changing our technology, but also our habits.

"To maximise reductions in emissions, it's necessary for stakeholders to work together, such as sharing in investments, sharing the rewards and sacrifices," says Dr Calleya. "Sacrifices at a consumer level could mean waiting longer for the next iPhone or buying more locally produced and grown goods."

Matthew Bolton
Science Writer
+ Matthew is a science and technology journalist based in the south-west of England. His particular interests include the history of space and space exploration. *@matthewbbolton*

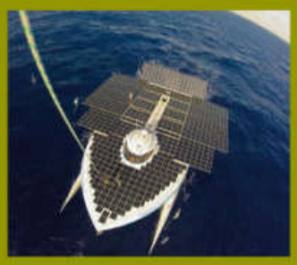
THE MOST DRAMATIC ECO-FRIENDLY SHIP CONCEPTS

A plethora of radical designs – and actual vessels – that could signal the next wave of green boats...

VINDSKIP

+ This design for a container ship turns the entire hull of the ship into a sail. It would constantly monitor the speed and direction of the wind to channel it along its hull, to run 'close haul', creating forward momentum even against the wind direction.

PLANET SOLAR



+ The MS Tûranor Planet Solar is a catamaran that runs entirely on those big, square solar arrays on its upper deck, but it needs careful sunlight management to maintain its movement. It can take 60 passengers and has made it around the world without too much trouble.

ECOLINER FAIR WINDS

+ This container ship concept relies on wind-assistance, packing four colossal sails to move the vessel at 18 knots. In a modern twist, the ship will monitor satellite and wind data to automatically find the optimum route and configuration for taking advantage of the wind.

SUPER-ECO SHIP 2030

+ A concept for a highly eco-friendly ship that 'might' launch in 2030 (hence the name). It not only features striking sails, but also retractable shells for its deck loads, which provide weather protection, but are also lined with solar cells. It would also use fuel cells designed to be the size of cargo containers as its main energy source.

IMAGE © THE TRUSTEES OF THE NATURAL HISTORY MUSEUM, LONDON, J. ZILHÃO, UNIVERSITY OF BARCELONA/ICRE

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